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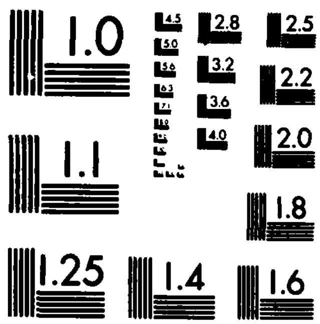
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DISTRIBUTION AND STORAGE OF AVIATION TURBINE FUEL FOR MILITARY OPERATIONS IN NORTHERN AUSTRALIA

THESIS

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Australian DoD

AFIT/GLM/LSM/84S-63

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Wright-Patterson Air Force Base, Ohio

AFIT/GLM/LSM/84

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THESIS

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

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Master of Science in Logistics Management

Denis Whitty, B.Ec.

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Abstract

In northern Australia, prospective economic development is unlikely to create a distributed network of aviation turbine fuel storages sufficient to support Australian Defence Force operations in an emergency, and Defence investment in fuel storage facilities and distribution resources might be required. This thesis project was an effort to identify the key relationships in the operational fuels system, and to create a decision support system capable of indicating broad relationships and tradeoffs between decision variables. To answer investigative questions arising from a broad system review, relevant literature was examined, indicating a need to focus on the distribution system with five key elements: (1) demand, (2) bulk seaboard storage facilities, (3) base storage, (4) transport resources, and (5) transport infrastructure. A simulation program was developed to directly represent system dynamics for distribution from bulk to base storage. Subject to correction of input statistics, the results could be used to inform Defence decisions on facilities construction, and investment in transport resources. With recommended enhancements, the model could potentially be used to inform Defence contributions to national and international policy considerations.

DISTRIBUTION AND STORAGE OF AVIATION TURBINE FUEL FOR MILITARY OPERATIONS IN NORTHERN AUSTRALIA

I. Introduction

Background

Australia is an island continent with an area of some 3 million square miles. It is a land of vast distances - 2,500 miles from east to west, and 2,300 from north to south. There are more than 22,000 miles of coastline, much of it deserted. "In the north and west, the coast is still largely virgin ground, untouched and waiting to be explored [6:69]."

The two dominant characteristics of the Australian climate, which ranges from tropical to temperate, are the extent and severity of seasonal aridity and the unreliability and great variability of precipitation from year to year. "Excluding the Antartic, Australia is the driest continent, with one-third of its entire land area within the arid zone [19:37]." Prolonged periods of drought will affect most of the country. When the rains come, they can be intense, and flooding is not uncommon.

Demographic patterns reflect the hospitality of the land, and are included in Figure 1 juxtaposed against a map showing landforms, precipitation and climate.

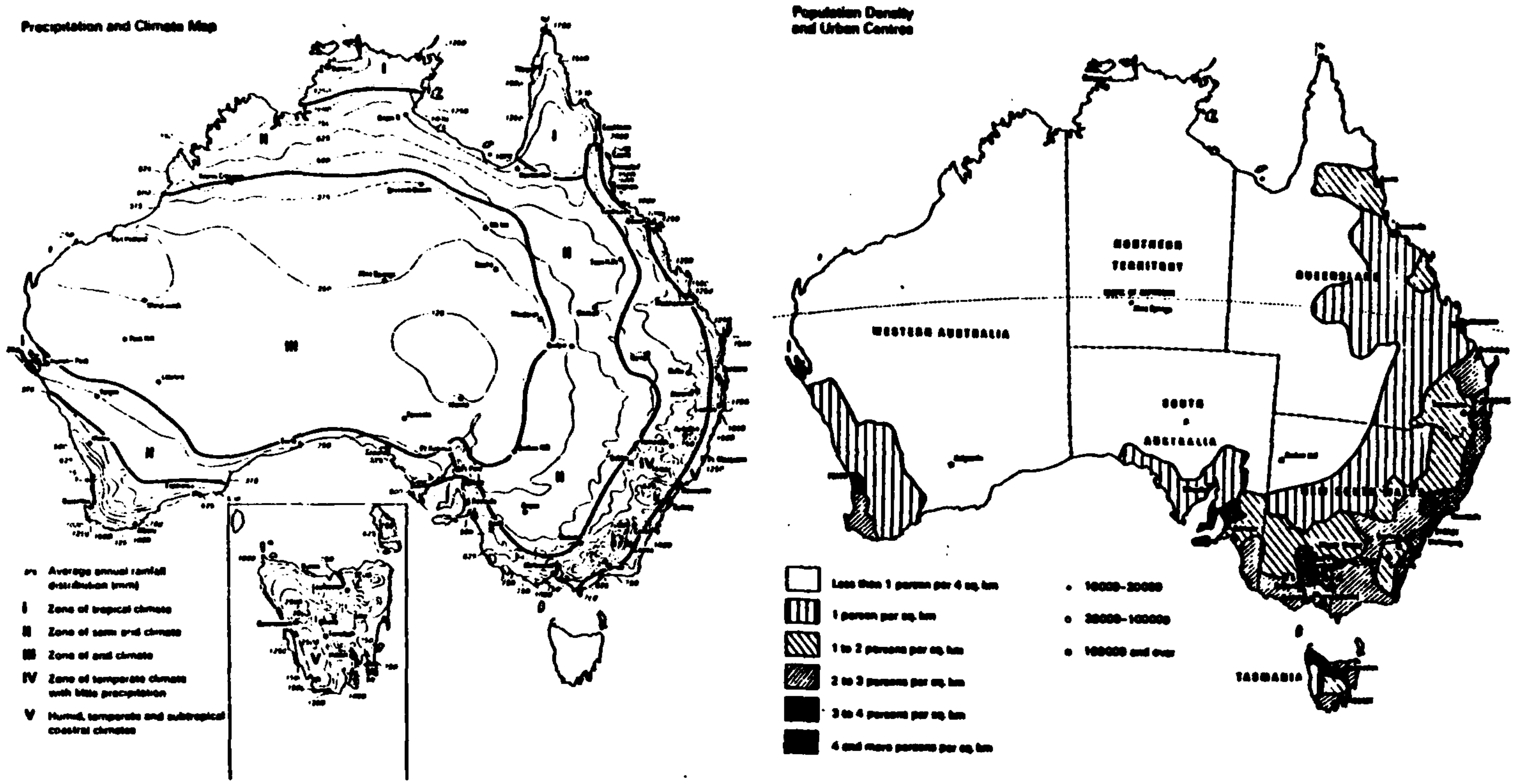


Figure 1. Australia - Precipitation and Population

Source: (19:38-166)

Industry clusters around the major cities of the south and east coasts. The ten largest cities hold approximately two-thirds of the people. The total population was some 14.574 million people in June 1981, with an average growth rate of around 1.86% per year (4:16).

In the north and north-west, industrial development is limited essentially to mining and grazing, and the population density is less than one person per square mile. Darwin, the largest town on the northern coast, has a population of only 30,000.

The basic facts underlying the shaping and conduct of Australian foreign and defence policy are that Australia is an essentially Western democratic society aligned with the United States and its allies and partners; it is also a relatively rich country in a populous, developing and rapidly changing region.

Historically, Australian military endeavors have been in defence of ideals rather than national territory. In World War I, initially in World War II, in Korea, in Malaya, and in Vietnam, Australian involvement was predicated not on a direct national threat, but on principles of freedom and democracy and antipathy toward totalitarianism. Australia shares no land borders with any other country, and the surrounding areas provide a significant barrier against adventurism by all but the most powerful of nations. Australian battles have been fought on foreign shores with logistics support being provided to varying degrees by larger allies.

However, the November 1976 White Paper on Australian Defence, presented to the Australian Parliament by the then Defence Minister, reflected a changing emphasis toward increased self-reliance.

> A primary requirement emerging from our findings is for increased self-reliance. In our contemporary circumstances we no longer base our policy on the expectation that Australia's Navy or Army or Air Force will be sent abroad to fight as part of some other nation's force, supported by it. We do not rule out an Australian contribution to operations elsewhere if the requirement arose and we felt that our presence would be effective, and if our forces could be spared from their national tasks. But we believe that any operations are much more likely to be in our own neighborhood than in some distant or forward theatre, and that our Armed Services would be conducting joint operations together as the Australian Defence Force [3:10].
>
> This self-reliant posture derives essentially from our own national interests and responsibilities. It also accords with our status as an ally of the US, for by accepting our local responsibilities we can contribute to the alliance relationship and to the US global effort [3:11].

This new emphasis on the defence of Australia itself brought with it a myriad of defence planning problems. History and propinquity to the Asian land mass indicate that the most probable direction of military threat to Australia is through the sparsely settled North, where there is no industrial support infrastructure, transport links are rudimentary, and military establishments are few and minor.

General Issue

Fossil fuels remain the lifeblood of military operations. Within the overall problem of logistic support for a force deployed to an inhospitable environment with extremely limited industrial infrastructure, the problem of fuel supply looms large. The area has no

refining capacity and limited storage. Petroleum products are imported from Singapore. Were that link to be denied, supply from the distant South might be required to satisfy civil needs as well as any increase in Defence demand. The broad management problem is whether, and, if so, how and when to allocate scarce Defence resources to a fuel storage and distribution system which would enable timely and continuous military operations, if they become necessary.

Specific Problem

Aviation turbine fuel (AVTUR) accounts for more than half of Australian Defence Force (ADF) consumption of operational fuels in peacetime. Usage could increase by a factor of four or more in an emergency. But in more than 2,500 miles of northern coastline, Defence storages for AVTUR have a total capacity of about 27,000 barrels. Given the high probability that prospective economic development would not create a distributed network of aviation fuel storages sufficient to support ADF operations in an emergency, initial exploratory research is required to identify the key relationships in the operational fuel distribution system (with particular reference to AVTUR), and, if possible, to create a decision support system capable of demonstrating broad relationships between decision variables.

II. System Review

A first step toward development of specific research questions and investigative questions involves decomposing the Australian Operational Fuels system to a final focus on aviation turbine fuel (AVTUR) using the ICAM Definition Method (IDEF). A condensed description of this method is attached as Appendix A. Essentially, a system is modelled by successive decompositions of a holistic overview into its component modules, revealing the basic elements and relationships.

The System and Its Environment

The aviation turbine fuel system (AVTUR) is not a stand-alone system, but rather a sub-system of the fossil fuels system, or perhaps from a different viewpoint a sub-sub-system of energy, and "what constitutes the environment of the sub-system should, for practical reasons and for a realistic solution, be part and parcel of the system itself [35:30]."

The essential objective of the system is to provide operational fuel for military use where and when needed, and the system operates within the organizational boundary of the Australian Defence Force (ADF). The broad inputs to that organization are government policy, incorporating strategic analysis, threat perception, preparedness requirements, force structure determination, activity level, and training and administrative requirements. The processes of the system are the processes of logistics at large, i.e., requirements determination, acquisition, distribution (including storage), and

consumption. The essential output is utility - measured against the input objectives, and assessed through formal feedback channels and formal and informal omnidirectional organizational links.

The environment of the system is coincident with the environment of the fossil fuels system because ADF usage of fossil fuels in peacetime is a relatively minor proportion of total national consumption. In a period of confrontation or armed conflict, the importance and influence of the ADF, and its share of consumption, would increase commensurately with the perceived threat.

The four major resource factors for production of any goods or services are labor, capital, land (raw materials), and equipment. The requirements for these pervade the fossil fuel system, with the mix changing for different processes. Technology exerts considerable influence but is not subject to control by the ADF or by the Australian fossil fuel system at large, which has miniscule influence on the world scene.

The transport industry, agricultural, mining, and manufacturing industries, and domestic users of fossil fuels will remain relatively larger users than the ADF and might have conflicting interests for all but high level operations.

Government policies on price stabilization of domestic crude influence demand by maintaining price parity with OPEC countries. Other Government policies (e.g., on environmental control, alternative energy sources) are environmental factors, as is the Government's perception of the international political situation and outlook, particularly as affecting the Middle East countries where imported crude is sourced.

While including the whole world in the environment of the system would make analysis unmanageable, the continuing dependence of the world economy on fossil fuels dictates that no excluding boundary can be defined.

The broad outlines of the system as perceived are portrayed diagramatically in Figure 2.

Basic Processes

The four basic processes in the system are seen as extraction, refinement, distribution, and consumption. These are modelled in Figure 3. The basic input is demand for petroleum products and the basic output is utility. The free market mechanism provides the feedback control loop of the conceptual model. At this level of abstraction the "mechanisms" or resources associated with each process need not be broken down further than the traditional land, labor, capital, and equipment. Those mechanisms are therefore assumed rather than portrayed.

The broad constraints of the system are geology, geography, technology, and economic infrastructure.

Extraction. The extraction process is modelled in Figure 4. Oil exploration in Australia is encouraged and subsidized by the Government, but not to the extent that risk capital is plentiful.

Data on prospectivity is the output of the exploration process. This may be detailed seismic information and/or core samples. Proving

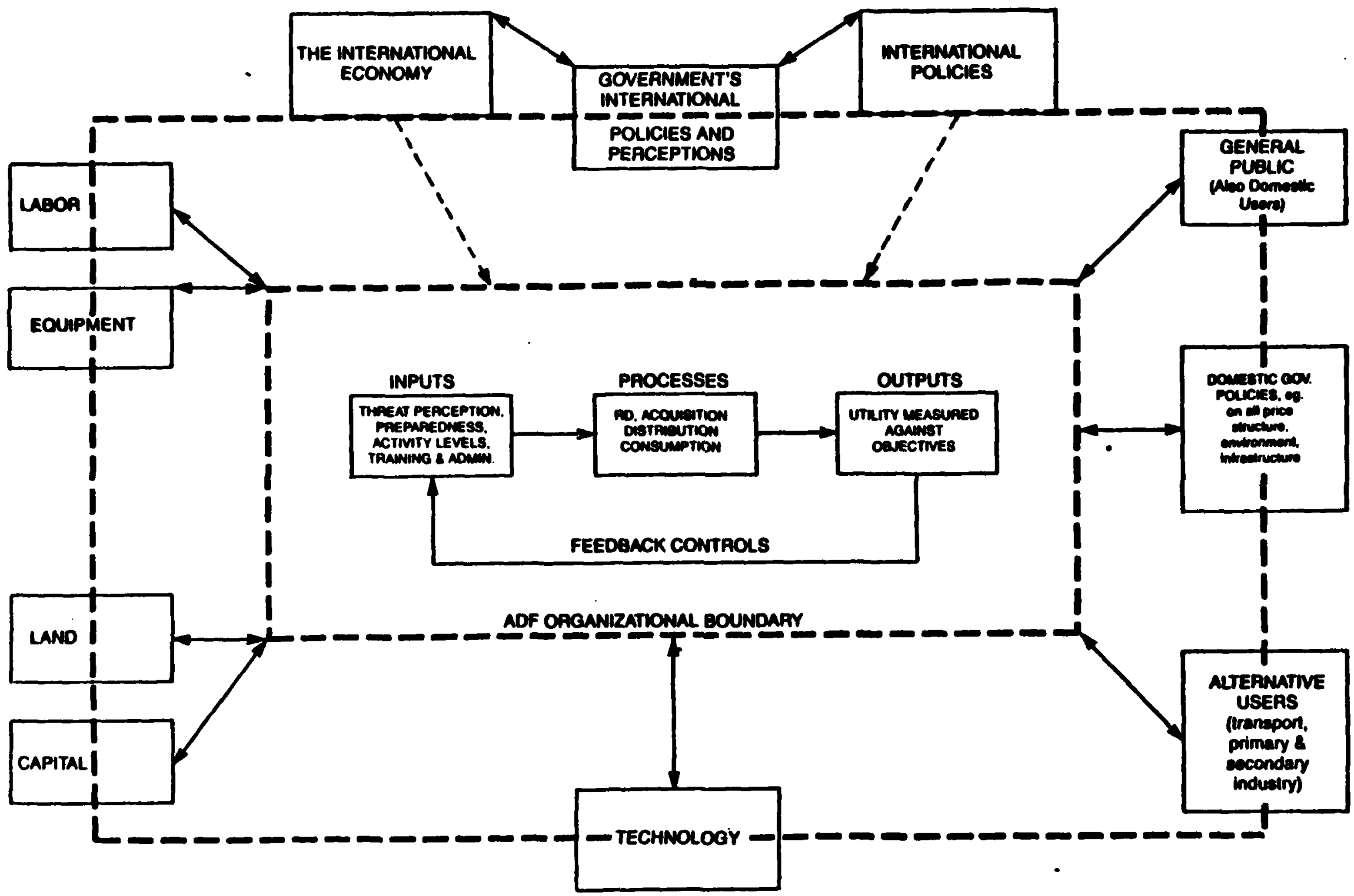


Figure 2: The Operational Fuels System - Environment

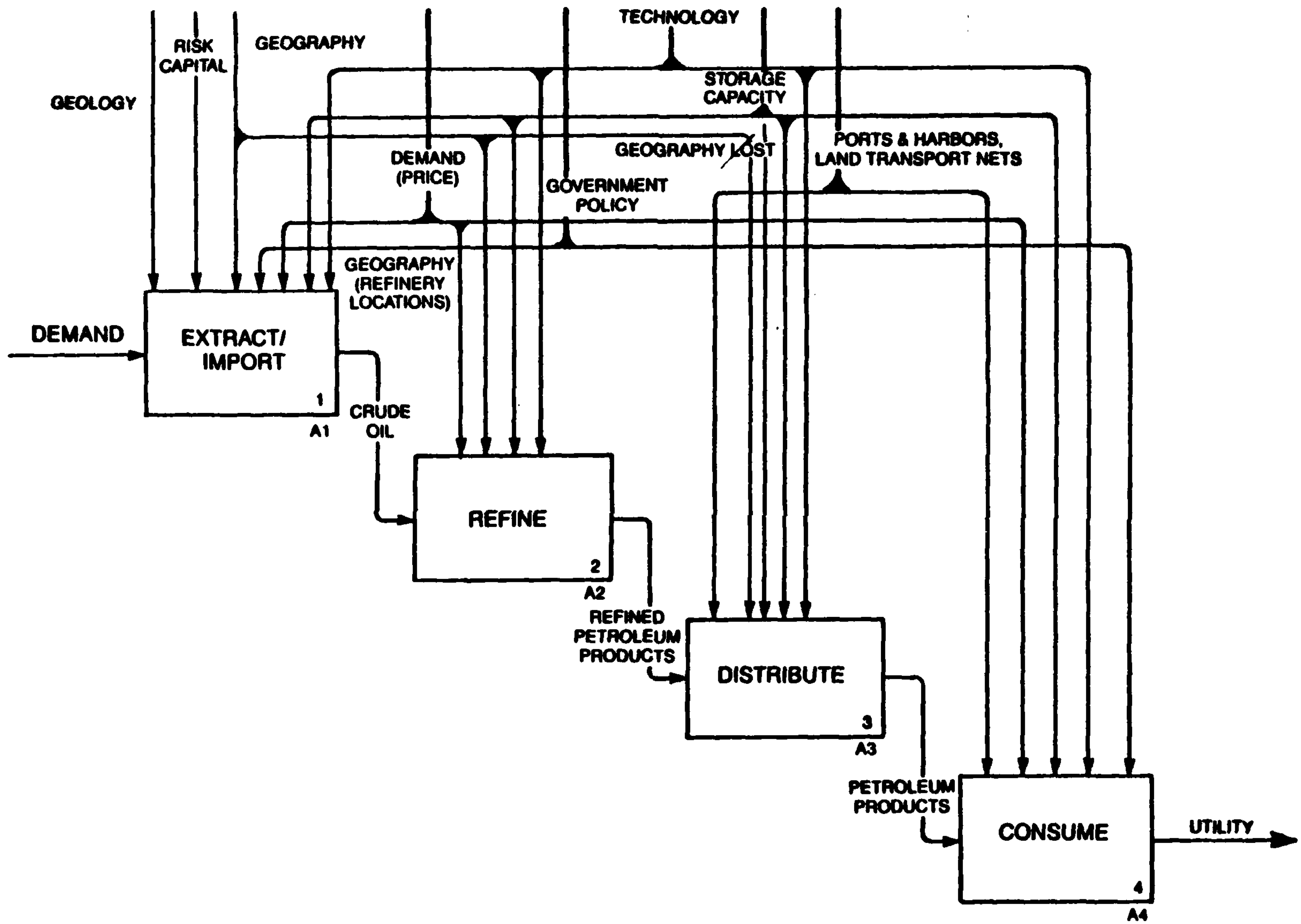


Figure 3. The Operational Fuels System - Basic Processes

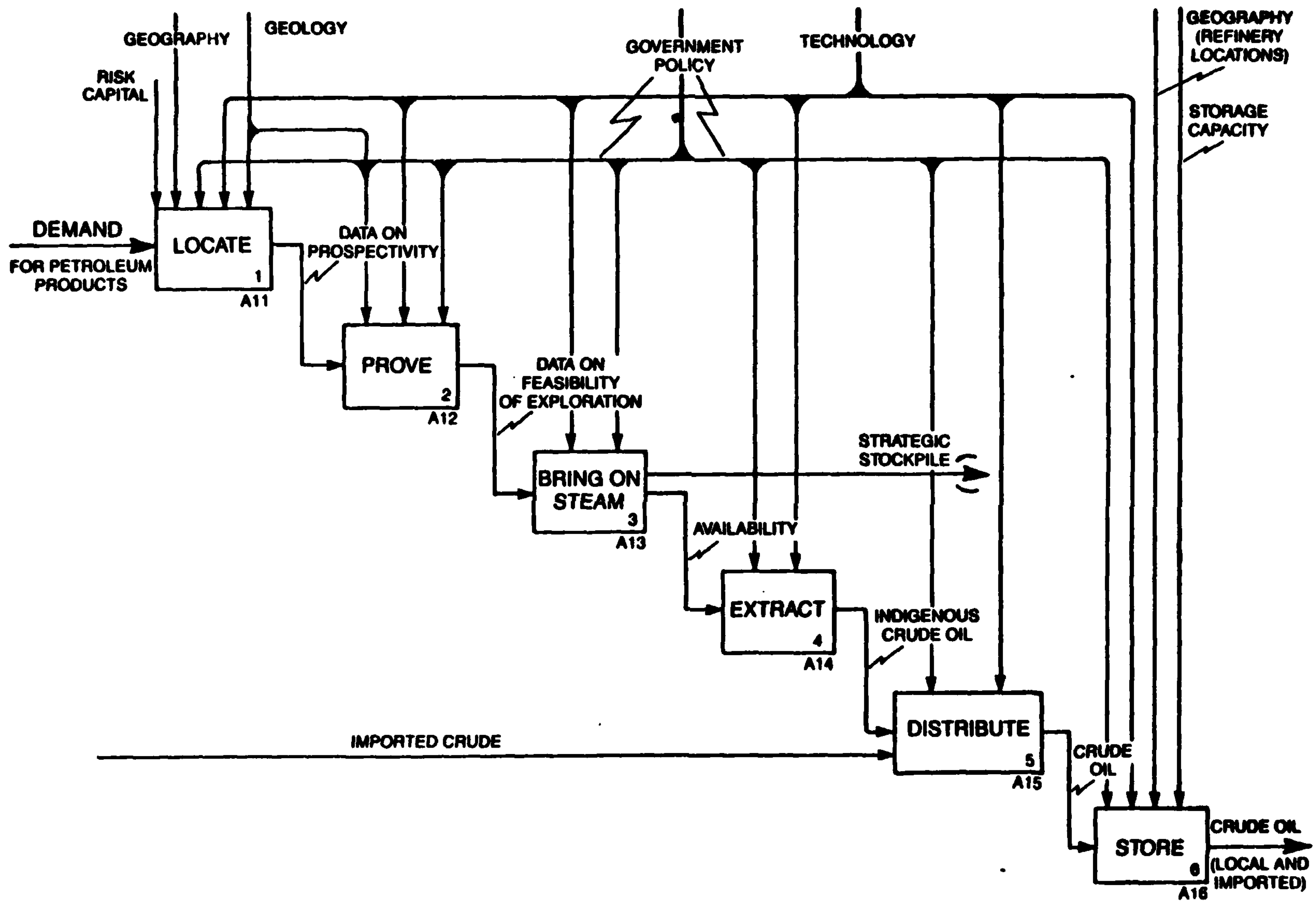


Figure 4. The Operational Fuels System - Extraction

the find requires further drilling to establish the extent of the field. If commercially viable, a platform will be erected from which initial production and further developmental drilling can take place.

There may then be a question of whether the oil should be left in the ground as strategic stockpile for delayed consumption or as readily available emergency feedstock. Presuming a decision to exploit, the extraction process, which has become more efficient with technological advances and more complete because of high ruling prices, can commence.

Distribution at this stage is limited to refineries (only refined product is exported and then on a small scale). Refinery storage capacity in a free market economy is normally based on economic considerations and perceived commercial requirements, taking no account of strategic needs.

Since Australia is not self-sufficient in crude oil production, some feedstock is imported, mainly from the Middle East.

Investigative Question. What is the present extent of Australian dependence on imported crude, and how is this likely to change?

Refining. The basic constraints on the Australian refinery system are technology and cost, including cost of distribution. Bulk storage capacity, geared to maximize profitability and therefore minimize inventory, is an additional constraint.

A model of the refining system is shown at Figure 5. AVTUR is a middle distillate which can be produced as a "straight run" product, i.e. by simple distillation in a crude distillation unit. But secondary

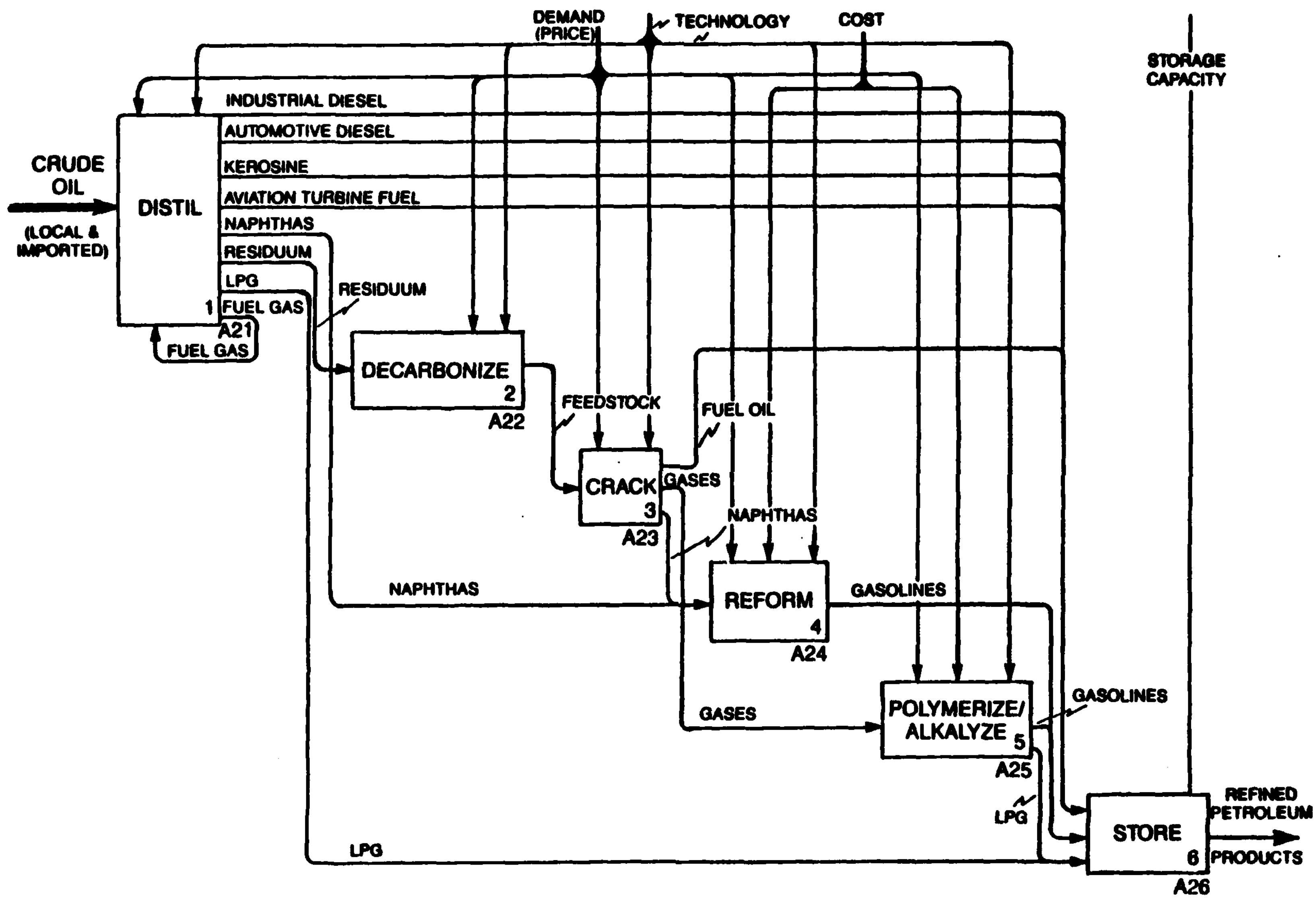


Figure 5. The Operational Fuels System - Refining

processing, e.g. catalytic cracking to convert heavier crude fractions such as fuel oil into 'white" products such as AVTUR, plays a vital role in matching the refinery output to market demand.

<u>Investigative Questions</u>. What is the overall Australian refining capacity and production pattern in terms of location, feedstocks, and output? What flexibility exists in refinery utilization and the composition of refined product output to increase production of AVTUR? What is the extent and location of bulk storage capacity for AVTUR?

<u>Distribution</u>. The fuel distribution system is modelled in Figure 6. Australian rail and road systems are comparatively limited and austere, essentially servicing the east and south-east. There is one cross-continent road and rail link from east to west which parallels the southern coast. There are north-south road links, but as yet no north-south rail link. Gross tidal movements in the north-west restrict the utility of many ports and harbors for unloading bulk tankers. There are therefore significant cost inhibitions on wide or speedy distribution within the continent which, in some areas, make importation of refined product an economically viable alternative.

<u>Investigative Questions</u>. What is the extent and pattern of import reliance for refined product, particularly AVTUR? What are the limitations on each transport mode, specifically for distribution from southern refineries to the North coast?

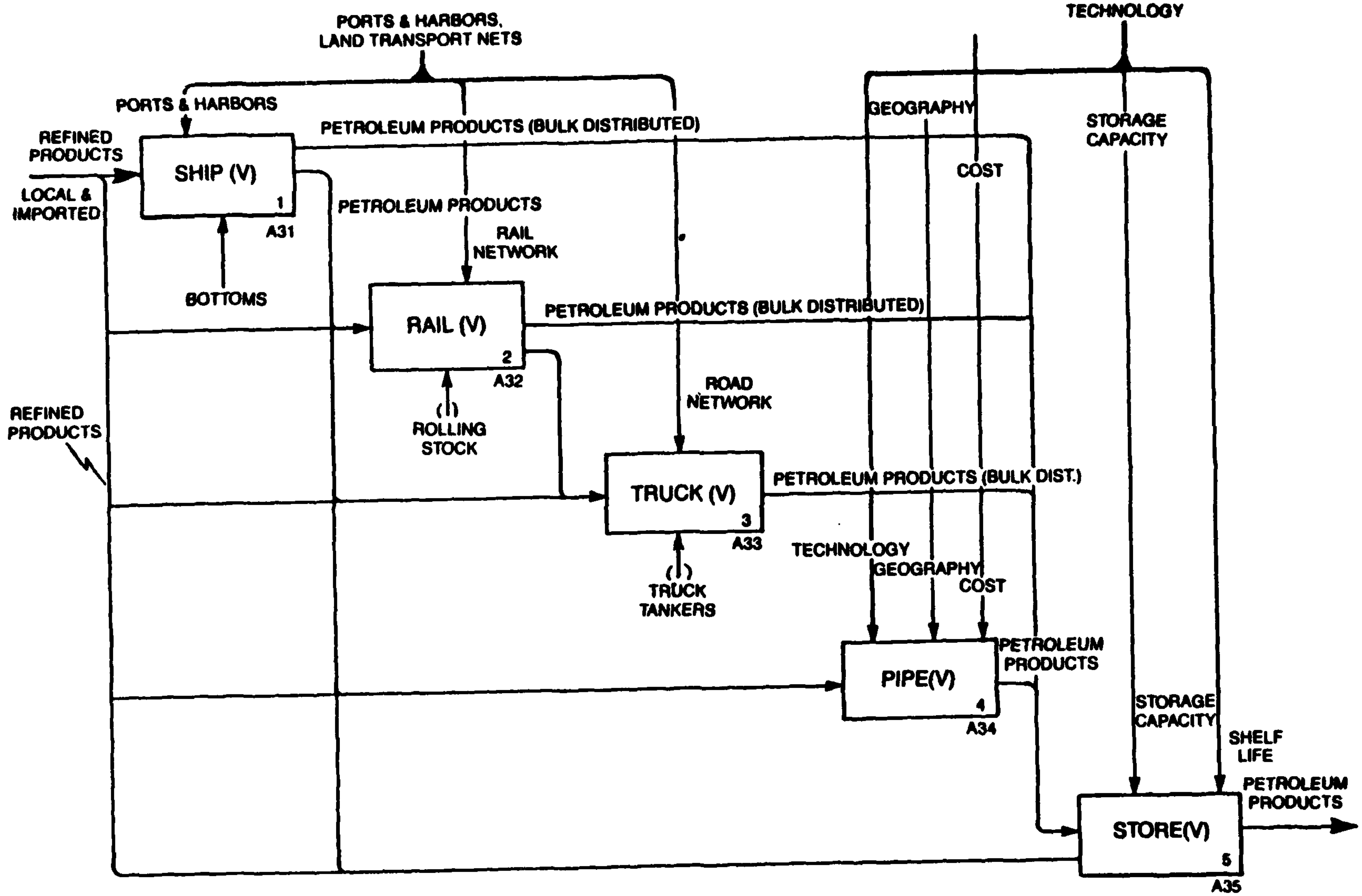


Figure 6. The Operational Fuels System - Distribution

Consumption. The consumption of fossil fuels is modelled in Figure 7. Technology exercises a basic constraint on all nodes. While advances in alternative fuel technology could marginally affect the fossil fuels consumption system in the longer term, there seems no present alternative to the considerable reliance on petroleum products for military operation.

Various Government policies are also significant in effect - there are constraints on pollution, inter-fuel substitutions, subsidization of farming and selected manufacturers, and particularly on the conduct of military operations.

The transportation process is both the major consumer of petroleum products and the distribution channel for most of the other users.

Depending on the nature of the contingency, the process of conducting military operations might involve deployment and operation of land, sea and air elements. Deterrence and/or defence would be the basic aim, embracing possible air missions of surveillance, reconnaissance, ground support, interception, interdiction, strategic strike and resupply.

Investigative Questions. How significant a consumer is the ADF in terms of national consumption? How is the peacetime consumption pattern likely to change in an emergency, both generally and with specific reference to Northern Australia?

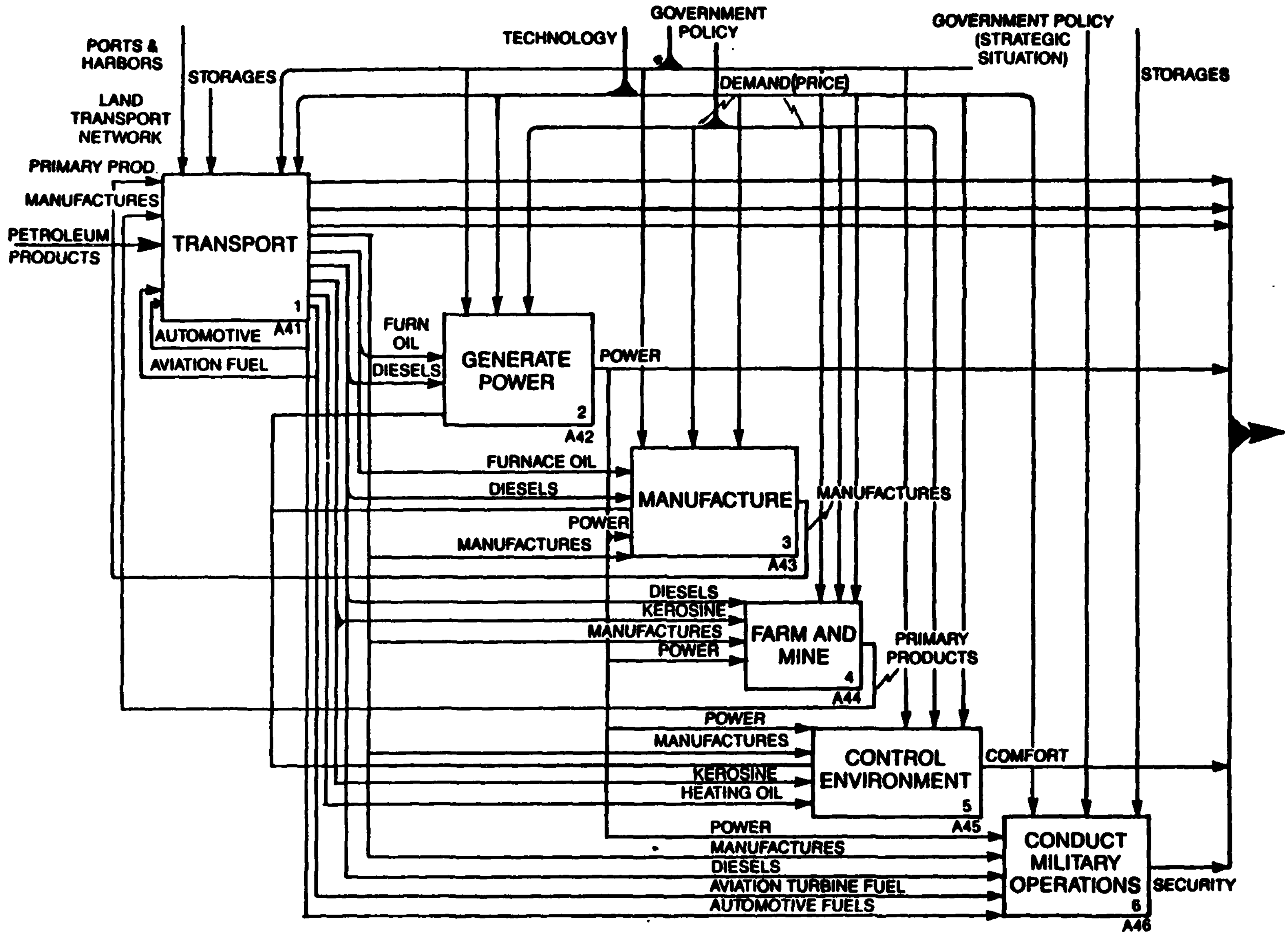


Figure 7. The Operational Fuels System - Consumption

III. Literature Review

There are several important investigative questions flowing from initial system analysis which provide a focus for literature review. In summary these are as follows:

1. What is the present extent of Australian dependence on imported crude, and how is this likely to change?

2. What is the overall Australian refining capacity and production pattern in terms of location, feedstocks, and output?

3. What flexibility exists in refinery utilization and the composition of refined product output to increase production of AVTUR?

4. What is the extent and location of bulk storage capacity for AVTUR?

5. What is the extent and pattern of import reliance for refined product, particularly AVTUR?

6. What are the limitations on each transport mode, specifically for distribution from southern refineries to the North coast?

7. How significant a consumer is the ADF in terms of national consumption?

8. How is the peacetime consumption pattern likely to change in an emergency, both generally and with specific reference to Northern Australia?

Dependency

Locations, nature and status of Australian petroleum discoveries are shown in Figure 8. Demonstrated recoverable resources of crude oil presently total some 1880 million barrels capable of economic exploration and a further 140 million barrels of subeconomic resources (28:31).

Australia's major crude oil field lies offshore in the south of the continent in Bass Strait. It contains approximately 78% of the country's proved and probable commercial liquid petroleum reserves (8:10). But with that major exception, the location of oil and gas fields does not correspond with the population distribution, and economic exploitation needs to take into consideration the potential for considerable transportation costs.

The present level of indigenous production of oil and condensate (low-vapor-pressure products which are contained as vapor in natural gas in the reservoir and become liquid at standard field separation conditions) is about 150 million barrels per year. This source provides approximately two-thirds of the total crude oil input to Australia refineries.

If no new oil discoveries are assumed, Australia's level of self-sufficiency in liquid fuels would decline from present levels to around 47% in 1991-92. However, there are reasonable prospects of new discoveries; the Australian Bureau of Mineral Resources has estimated that there is a 50% probability of finding more than 1800 million barrels of oil in Australia in the foreseeable future (11:11). Official forecasts accordingly estimate that self-sufficiency in 1991-92 could be around 80% (11:11).

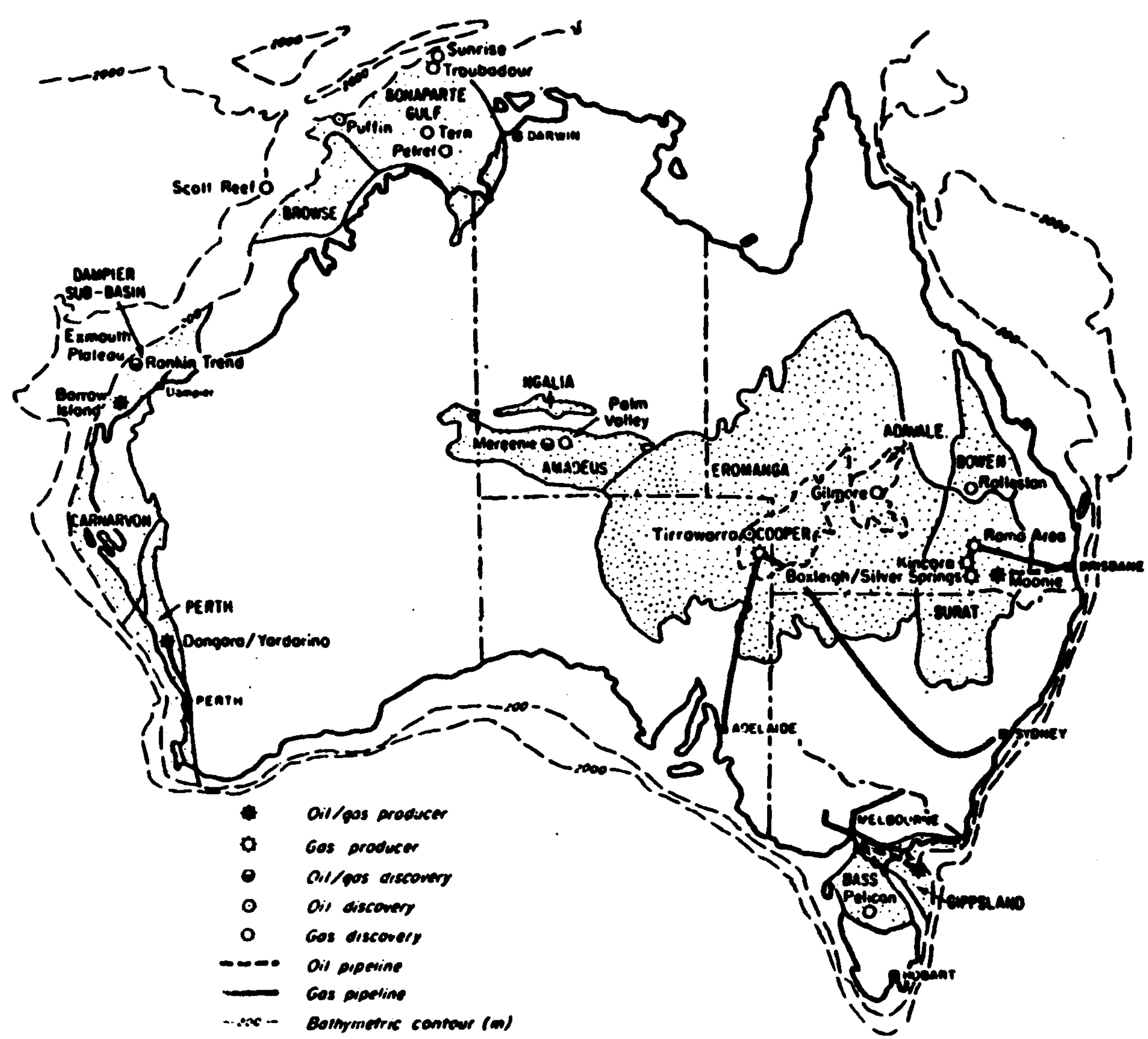


Figure 8. Location and Status of Australian Petroleum Discoveries

Source: (28:30)

However, dependency is not necessarily indicated by an estimate of self-sufficiency. At a self-sufficiency level of 80%, the imported 20% may be critical. In the Australian case, the greatest effect of a reduction or cessation of crude oil imports would be on the supplies of heavier products such as lubricants, greases, and fuel oils. Indigenous crudes are light by world standards and consequently yield higher proportions of gasolines, kerosines, and the middle distillates (including AVTUR). In 1981, the Australian National Petroleum Advisory Committee (NPAC) examined the effects of three representative scenarios of supply disruption which involved: (1) 100% loss of imported crude and products, (2) 50% loss of imported crude and products, and (3) 50% loss of indigenous crude, replaced by imports. The NPAC concluded, inter alia, that "a significant cut in motor spirit and AVTUR supplies, both of which are considered to have a significant level of discretionary usage, would possibly be manageable without severe difficulties [31:xiii]."

In the longer term, estimates of Australian self-sufficiency are supported by the existence of considerable deposits of oil shales for which demonstrated and inferred subeconomic resources represent some 650 times as much oil as Australia's presently identified recoverable resources of conventional crude (28:38-39).

Refining Capacity and Flexibility

There are eight major oil companies operating eleven refineries in Australia. The refinery locations and names are annotated in Figure 9 together with primary distillation capacity measured in barrels per

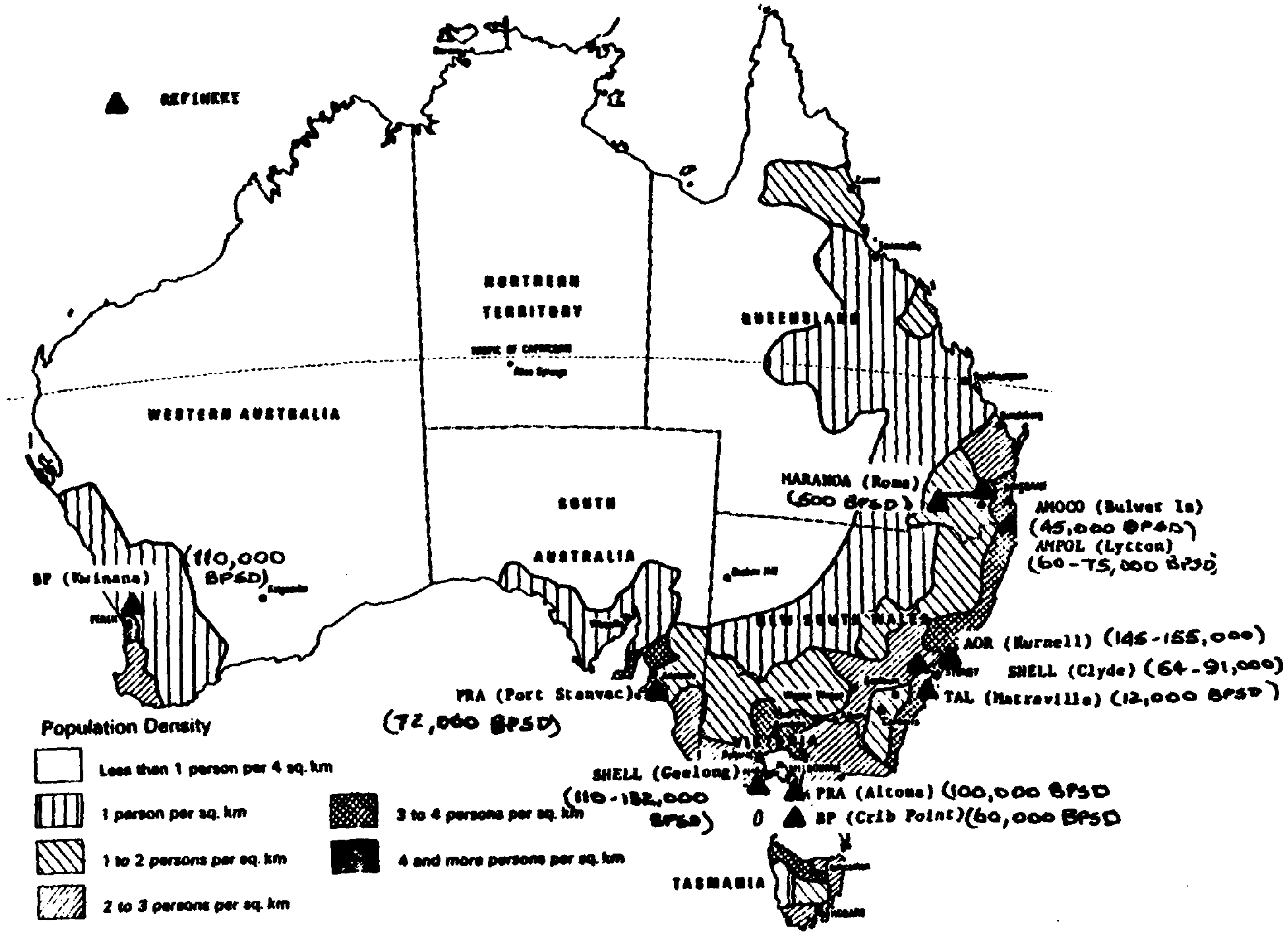


Figure 9. Refinery Locations and Capacity (barrels per stream day)

Source: (9:14)

stream day (statistics from 9:1). Table I shows typical product slates for the eleven refineries. All but two produce AVTUR. One exception is insignificant (ROMA, with throughput of only 500 barrels per stream day). The other, Bulwer Island, could produce AVTUR if necessary.

Certain refineries have been dedicated to process a high proportion of indigenous crude. Kwinana, in Western Australia, is optimized to take Middle East feedstocks. The local crude is a light oil yielding a high proportion of straight run liquid transport fuels, including AVTUR, through simple distillation. Depending on the demand mix, more complex refining processes are undertaken to produce a higher proportion of a given product than is available from the "straight run" process. Approximately 25% of Australian refinery capacity is not utilized (9:15).

Demand for AVTUR in the Australian market is increasing at a growth rate of around 3% per annum. Domestic consumption in 1980-81 was around 2074 ML while refinery production was 2293 ML (the additional 10.5% was exported) (9:12). A survey of the industry conducted in 1981 indicated that despite the projected increase in demand for middle distillates, significant additional proportions of these products can be obtained with only minor modification to the existing refinery system (9:15). Catalytic cracking, for example, can increase the yield of middle distillates by about 10% (9:59) and hydrocracking by a further 12% (9:63).

In addition, the Australian product specification for AVTUR is very rigorously specified so that the possible yield from crude oil is limited. The critical inhibitors are the flash point (set at 38°C) and

TABLE I

Typical Product Slate for Australian Refineries - 1982

REFINERY	LPG	AUTOMOTIVE GASOLINE	AVIATION GASOLINE	AVIATION TURBINE FUEL	LIGHTING KEROSINE	POWER KEROSINE	HEATING OIL	AUTOMOTIVE DIESEL OIL	INDUSTRIAL AND MARINE DIESEL OIL	FUEL OIL	BITUMEN
AMOCO (Bulwer Is)	X	X			X		X	X		X	X
AMPOL (Lytton)	X	X		X	X	X		X	X	X	
AOR (Kurnell)	X	X		X	X		X	X	X	X	X
BP (Kwinana)	X	X	X	X	X		X	X	X	X	X
BP (Crib Point)	X	X		X			X	X		X	X
MARANOA (Roma)		X						X		X	X
PRA (Altona)	X	X	X	X	X		X	X	X	X	X
PRA (Port Stanvac)	X	X		X	X		X	X	X	X	X
SHELL (Clyde)	X	X		X	X		X	X	X	X	X
SHELL (Geelong)	X	X	X	X	X		X	X	X	X	X
TAL (Matraville)				X				X			X

X Indicates that product is in refinery slate.

Source (9:14)

the freezing point (set at minus 50°C). As a basis for comparison, aviation turbine fuel with a freezing point of minus 40°C is used by domestic airlines in the U.S.A., and aviation turbine fuel with a flash point of 32°C is used in Canada. It has been calculated that:

> by relaxing the [Australian] flashpoint restriction by 3°C, (from 38°C to 35°C) and lowering the freezing point restriction by 2°C (from minus 50°C to minus 48°C), the yield of aviation fuel from Gippsland [Bass Strait] crude oil could be increased by one third [9:14].

In summary, available information would support a conclusion that the Australian refinery capacity is sufficiently large and flexible to meet a quite considerable increase in demand for AVTUR.

Storage and Distribution

From the refineries, the major portion of refined product passes firstly to seaboard bulk storage installations located around the Australian coast and thence to retail outlets and/or commercial bulk users in the immediate vacinity.

Seaboard bulk storage capacities for AVTUR are shown in Table II together with the refineries which supply them.

Of note is the extent of the reliance of northern locations on Singapore resupply. Singapore has become increasingly important as a supply source to this area because it is more economical to supply remote market areas from abroad rather than transport products from domestic refineries.

> Despite the fact that imports of refined petroleum products only constitute a small proportion of total Australian consumption, they are of particular significance .

TABLE II

AVTUR Bulk Storage Capacity (Megalitres)

Location	Refinery	Seaboard Installation	Prime Resupply
NSW			
Sydney	86.17*	15.20	Refineries (Kurnell - 69%AS;
Newcastle		6.33	Matraville - 35%AS; Clyde - 75% AS) Sidney
VIC			
Melbourne	64.56	27.94	Refineries (Geelong -83%AS; Altona - 94%AS; Westernport - 98%AS)
TAS			
Bell Bay)	'	3.88	Melbourne
Hobart)			
QLD			
Brisbane	19.00	25.32	Refinery (Lytton - 65%AS)
Cairns		6.33)	
Gladstone		2.53)	Brisbane
Mackay		5.15)	
Townsville		12.66)	
Weipa		0.51	Singapore
SA			
Adelaide	11.39	24.14	Refinery (Port Stanvac - 20%AS)
Pt Pirie		1.26	Adelaide
WA			
Perth (Kewdale (Fremantle	45.58	10.13	Refinery (Kwinana - 30%AS)
Broome		0.76	Singapore
Carnavon		1.14	Singapore (2000 tonnes limit on shipping)
Pt Hedland		5.78	Singapore
Derby		1.26	Singapore
Wyndham		0.88	Singapore
NT			
Darwin		25.32	Singapore
TOTAL	226.68	181.68	

Source: Unpublished and unreferenced documents provided by the Australian Department of Defense

. . as a regular source of supply (from Singapore) to the Northern Territory, the north west of Western Australia and North Queensland [31:12].

In 1979/80 three quarters of the Northern Territory's AVTUR and 14% of Western Australian consumption of AVTUR was sourced from Singapore (31:12).

Rail Transport Limitations. The Australian railway system is not only limited in extent. It is comprised of six different systems developed by the different states, and there are compatability problems between adjoining systems because of differing track guages which require different rolling stock.

Three different track guages are still in use - (broad guage (1600mm); standard guage (1435mm); and narrow guage (1067mm). The coverage for each is shown on the map at Figure 10. Rail transport of petroleum products from southern refineries to the north coast is simply not an option, either for primary resupply or to provide redundancy.

Road Transport Limitations. One of the Australian stated priorities is an adequate system of National Highways. Current programs to upgrade roads in northern Australia give emphasis to sealing unsealed road sections and improving flood immunity. But at present, unsealed road sections still exist, even on "major" connecting routes.

Unsealed road sections may vary from good gravel to bumpy, corrugated earth formations where rocky outcrops, sandy stretches and bulldust patches can cause hazardous driving conditions. Even light

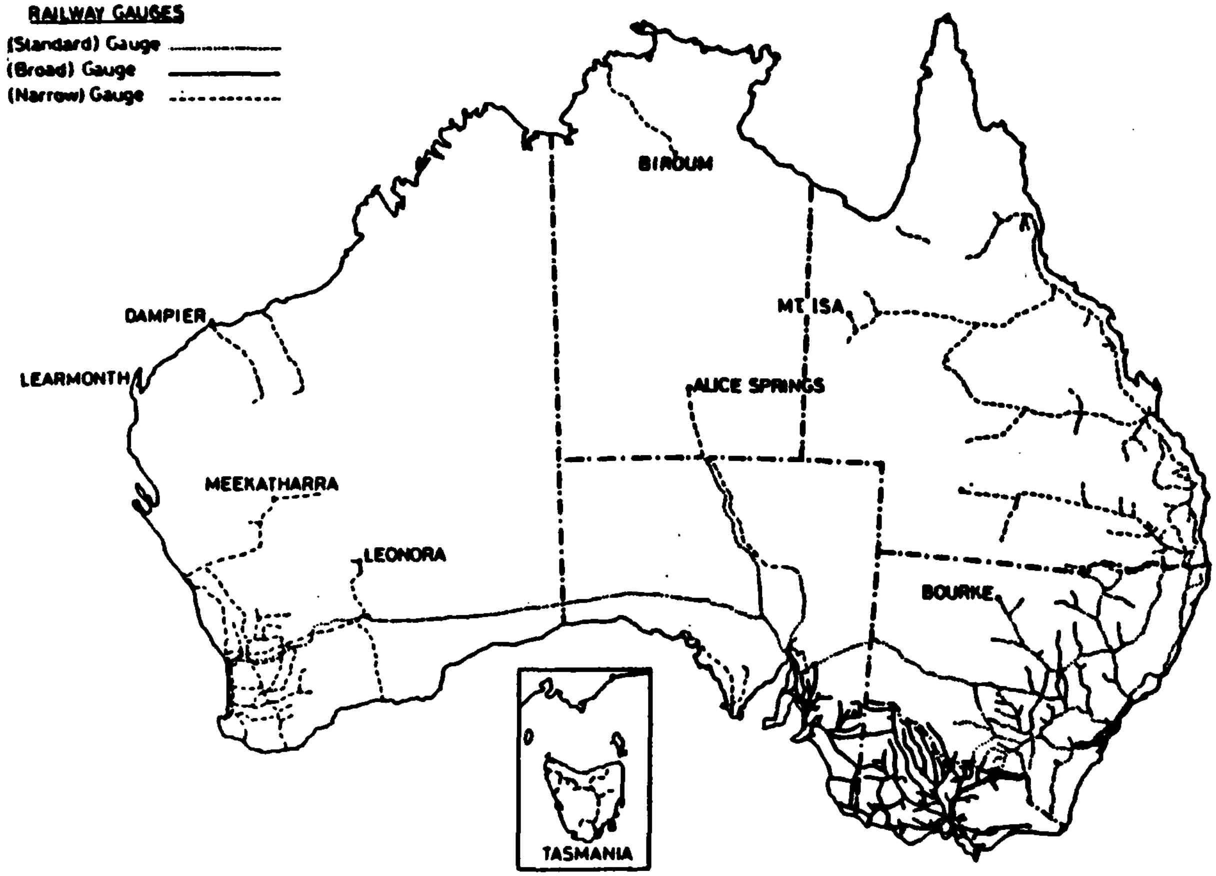


Figure 10. Australian Railway System

Source: Unpublished, unreferenced papers provided by Australian Department of Defence

rainfall has adverse effect. Between December and March, monsoon rains can make driving in Northern Australia impossible, because rivers and low lying areas are subject to flooding.

The Australian networks of major roads is shown on Figure 11, together with possible operational sites in the North West and the extent of railway coverage.

Defence Force Consumption

In order to maintain operational capabilities in peacetime, the ADF has an annual demand of between 1% and 2% of national consumption of the major transport fuels. The key Defence fuels are the middle distillates which comprised 78% of ADF consumption in 1979/80 and are expected to rise to 90% of fuel needs by 1990 as usage of aviation gasoline and fuel oil is phased out. AVTUR consumption represents some 56% of total Defence usage.

Should ADF activity expand to maximum operating rates in a time of international tension, its fuel requirements could increase substantially, perhaps by a factor of three or four, taking Defence demand to around 6% of normal national consumption of transport fuels.

Summary of Literature Review

At least within a ten year planning horizon, the review of literature indicates that Australia has sufficient lack of import dependence to support an assumption that adequate feedstocks for production of AVTUR would be available from local crude oil production.

Similarly, it can be assumed with some confidence that refinery capacity is adequate to fulfil considerably increased requirements for

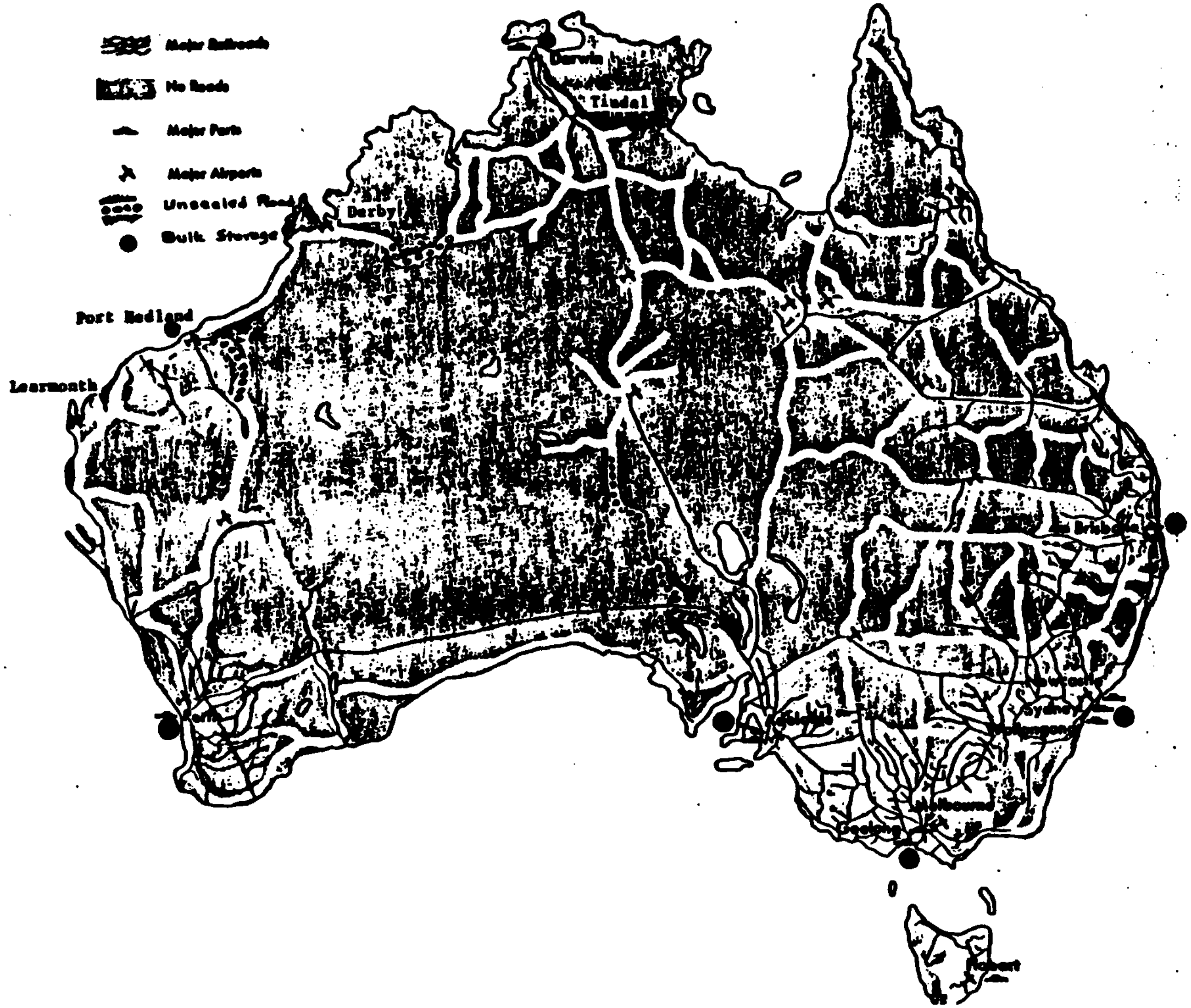


Figure 11. Geographic Locations and Transportation Nets - AVTUR

Source: Basic map from World Book Encyclopaedia

AVTUR either by taking up the slack in refinery capacity, by manipulating the product slate, by relaxing specifications or by a combination of all three methods.

The central focus of the research question then becomes the distribution system, with five key elements: (1) demand level, (2) storage capacity at destination, (3) bulk seaboard storage capacity, (4) transport resources, and (5) infrastructure. Demand, bulk seaboard storage, and local storage capacity would determine the size and necessary frequency of order both by consumer and bulk installation. Availability of fuel transport resources, and the nature and reliability of transport infrastructure, would determine the time for resupply and its fluency.

Basis for Experimentation

To usefully examine these elements requires firstly the choice of an appropriate response variable.

The essential requirement for any operational air base is to be mission ready, and in a situation of uncertain or weather-dependent replenishment of fuel stocks, there would be occsions when a prudent commanding officer would need to halt normal operations and conserve fuel holdings against emergency requirements. Such requirements might include priorty missions ordered by a higher headquarters, search and rescue, and point or zone defense. The period(s) during which a base is in this hiatus state - idle time - should provide a meaningful indication of the effectiveness of the fuel distribution system as a whole.

Obviously, if the system is optimized to meet operational requirements, idle time would normally be constant at zero value, with perturbations caused only be acts of war or acts of God. But in peacetime, and in preparation for possible contingencies, different system criteria might be in order, e.g., minimize idle time subject to cost or resource constraints, or minimize cost subject to one or more operational constraints.

A decision support system capable of assessing the potential occurrence of idle time and its response to changes in such factors as bulk seaboard storage capacity, on base storage, demand levels and tanker truck resources would provide a range of options to inform different system criteria.

At present, no such defense oriented decision support system exists. National planning for a liquid fuels supply emergency is, logically, concerned mainly with economic and social considerations and the actions necessary to last out a finite non-military contingency. Defense planning is informed by military exercises held in the area from time to time, but logistics aspects of those infrequent exercises are essentially judgemental and subjective, and are sometimes subordinated to operational imperatives which make post-exercise data analysis difficult.

IV. Methodology

Determination of whether and in what manner variables are related to each other accords very closely with Emory's definition of experimentation (12:330). The question of "in what manner?" (concomitant variation) is the crux of the investigative/measurement question in this case, since there is an intuitive relationship between the variables.

However, the system under study is widespread and complex as it exists, and the interest lies in the effect of hypothetical changes or enhancements. Very few alternatives could be explored in real life experimentation even by setting up prohibitively expensive field exercises which would also be disruptive to the civil/commencial community. Particularly in this context

> The concept of simulation is both simple and intuitively appealing. It allows the user to experiment with systems (real and proposed) where it would be impossible or impractical otherwise [36:ix].

Simulation Experimentation

The essential concept of simulation is one of conducting experiments on a model of a system. A broad definition is "the technique of solving problems by the observation of the performance, over time, of a dynamic model of the system [13:39]."

Compared with the analytical solution of systems, simulation has some advantages and some disadvantages. If an analytical model can provide a parametric representation of a system which captures

the system's dynamics and is mathematically tractable for purposes of finding optimal solutions, then an analytical model should be used. But infinitely complex reality often cannot be simplified sufficiently to allow representation even by very complex methematical models. Simulation does not assure optimal solutions, but it allows representation of system dynamics without the same need to develop rigorous and complex mathematical models. A single run of a simulation model provides one point outcome from an array of possible outcomes, and the replication feature of simulation models can be used to draw out the system's properties and inter-relationships in a way which provides insight for managers into the value of possible decision alternatives.

"In many simulation studies a large amount of time and money is spent on model development and programming, but little effort is made to analyze the simulation output data in an appropriate manner [18:938]." The basic problem is that "classical statistical techniques based on independent identically distributed [i.i.d.] observations are not directly applicable [18:984]" since the output data from virtually all simulations are autocorrelated, and are also nonstationary rather than identically distributed.

Classical estimates of population mean μ and variance σ^2, assume observations are i.i.d. random variables, and their use in constructing a confidence interval (C.I.) for μ, usually assume a normal distribution. For terminating* simulations there are acceptable procedures for most statistical problems of interest because each replication produces an independent "observations." But for

steady-state* simulations there are several statistical problems with which special care must be taken. Replication and batch means are the most promising methods for estimating the steady-state average response, but any momentary equilibrium condition will be a function of subjective decisions taken already or yet to be taken, and intuition plays a large part in such estimates.

The "problem of the initial transient," or "start-up" problem, acknowledges the fact that it is generally not possible to choose initial simulation conditions precisely representative of steady-state behavior. The most common problem solution is deletion of initial data. This is seen to be generally advisable providing sufficient care is taken to determine an appropriate data truncation point. An acceptable alternative approach is to try to start the simulation in a state which is representative of the steady-state distribution - perhaps obtained from a pilot run.

A simulation model should be practical as well as personally gratifying. The dual need is summarized succinctly by Anshoff and Hayes who point out that:

> Researchers tend to judge their models by their quality. They define a high quality model as one that is <u>nontrivial</u>, <u>powerful</u>, and <u>elegant</u>. A model is nontrivial if it leads to insight into the system not readily perceivable by direct observation; powerful if it provides a large number of nontrivial insights; and elegant if the structure can be kept simple and if it runs efficiently on the computer.

---

* A terminating simulation ends if a specified event occurs. In a non-terminating or steady-state simulation the desired measure of performance for the model is defined as a limit as the length of the simulation goes to infinity [18:990]. For some systems, either or both types of simulation might be appropriate.

> Managers, on the other hand, . . . are concerned with pragmatic action decisions and tend to judge a model by its applicability. From their viewpoint, an applicable model is <u>relevant</u>, <u>valid</u>, <u>usable</u>, and <u>cost-effective</u>. A model is relevant if it deals with problems of importance to the manager; valid if a high degree of confidence can be placed in any inferences drawn from it; usable if it provides acceptable solutions that can be implemented; and cost-effective if the improvement it makes possible exceed the expense of developing and applying the model [quoted in 36:252].

The obstacle of dual orientation is often reinforced by what amounts to a language barrier between researcher and manager. The operations research/management science vocabulary can confuse and confound as well as enlighten, unless great care is taken to ensure managerial understanding of the basic assumptions, processes and results of the simulation exercise. This is particularly true of a model which addresses a hypothetical situation.

Validation of a model also presents particular problems. There are many concepts of validity, but the one most used in simulation literature treats validation as testing the agreement between the behavior of the model and that of the real system (36:210; 2:9). In the absence of a "real" system against which to test a hypothetical model, the achievement of internal validity - confirmation that the model is behaving as intended - combined with high "face validity" - an informed and authoritative judgement that the model is a reasonable approximation of the likely reality - would seem the most useful techniques available for validation.

Experimental Design

The final model should have as basic experimental design criteria the desirable qualities listed in Shannon (36:264-265) as being: (1) understandable to the user, (2) capable of giving reasonable answers, (3) capable of giving implementable answers, (4) realistic in data requirements, (5) capable of giving answers to "what if" type questions, (6) easily modified, and (7) cost-effective in use.

The objective of the experimental design is therefore to construct a simulation model which incorporates the above criteria and which, with appropriate input, can quantify the relationships between idle time and the key elements of the operational fuels system, identified as: (1) demand level, (2) storage capacity at destination, (3) bulk seaboard storage capacity, and (4) transport resources and infrastructure.

In this, the number of possible combinations of factors and levels of interest is huge in itself. Added complexity results from the need for defence-related experimentation to take into account the infinite uncertainties various stages of confrontation or combat.

Assumptions. As a first step toward development of a tractable model, experimentation is limited to a basic scenario of low level confrontation, where the hostile objective to be countered is imposition of political will rather than force majeure, but where there may be minimal warning time and some risk of escalation. A medium level contingency or conflict would be more likely to involve conventional

military deployment and operations rather than dispersed preparedness and surveillance, but potential Air Force operational locations would be the same and mainly demand rates would differ.

Geographic locations mentioned in the following paragraphs have been indicated on the map at Figure 11, which shows also the land transport infrastructure.

For the purpose of the experiment, supply of AVTUR from Singapore is assumed to have ceased, and Air Force operations are conducted from four joint civil/military use airfields at Darwin, Tindal, Derby, and Learmonth. Civil operations are assumed to continue normally in a lower level contingency.

Structural Model. The initial resupply concept is based on prime reliance on seaboard replenishment from Perth using seaboard bulk storage capacities for AVTUR at Darwin and Port Hedland as distribution hubs, Darwin for three operational airfields and Port Hedland for one operational airfield (because of the size disparity between existing bulk seaboard storage capacities at the two locations). Local distribution from Darwin and Port Hedland is assumed to be by short haul land transport. System redundancy and supply supplementation (not modeled) would rely upon long haul land transport from the Perth and Adelaide refineries.

A schematic diagram of the structural model of the starting system is at Figure 12, and the proposed treatment of the variables is summarized in Table III.

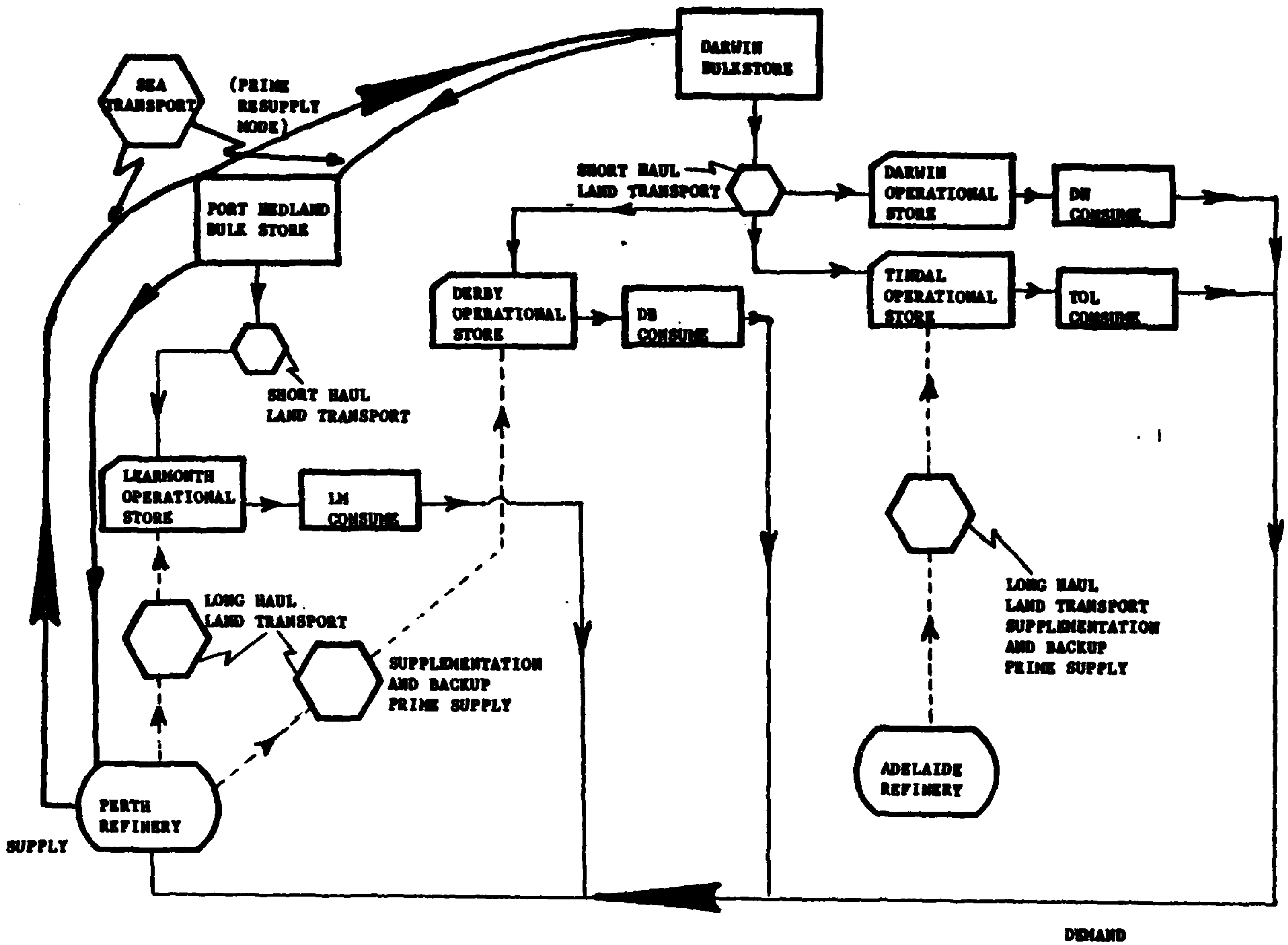


Figure 12. Structural Model of a Possible AVTUR Resupply System

TABLE III

Variable Disposition

Variable	Disposition in Model
Indigenous and imported crude flow	Assume adequacy
Number of refineries	Limit to two source refineries - Perth only for sea transport, Perth and Adelaide for land transport.
Feedstock type and quantity Refinery capacity, and complexity, product mix Specification requirements	Assume necessary action to provide adequate supply of AVTUR.
Refinery storage capacity stock level (AVTUR) Production runs Industrial actions Past Present	Assume adequacy and immediate availability for Defence Force requirements.
Time to order	Assume instantaneous time to order (standing order and high priority).
Time to obtain carrying vessels	
Sea	Assume dedicated ship as primary resupply mode.
Road	Assume dedicated resources.
Rail and road	Disregard as an option because of interchange requirements.
Time to transport (sea)	Assume one ship (unprotected) and fix time to transport (ship)
Time to transport (road) Varied by: Vessel capacity Speed Route Weather	Calculate short haul land transport fleet requirement for hub distribution based on bulk seaboard storages.
Bulk seaboard storage	Fix at present values initially. Later to assess effects of change.

TABLE III (con't)

Variable	Disposition in Model
Civil airfield storage Air Force airfield storage Storage configuration	Fix at existing capacities initially. Later vary to assess effects of change
Civil demand rate Air Force demand rate Aircraft numbers Aircraft types Sortie rate Maintenance/supply	Assume continuation of domestic and international flights, but aggregate civil and military demand as a total rate.

Interdiction of sea lines of supply is not envisaged in a lower level contingency, and protected passage could be assumed otherwise. The time to resupply in bulk by ship within a given supply cycle is therfore assumed to be constant. Aggregated average daily demand, the total of civil and military requirements, is assumed to be fixed. An enhanced model might treat demand as a dynamic factor based on various concepts of operations, but that option leads to clasified research and is not pursued herein.

Bulk seaboard storage capacity and on-base storage capacity are treated as factors or independent variables operating at different levels (and locations) for different experiments.

Procedure

The simulation will be a steady-state simulation. There is a terminating element implied in the system constituting the initial deployment and building up of operational capability. But this would be

a one-time effort for which necessary resources would be made available. The major interest is in sustained system performance, and the resources required to achieve this.

To summarize, the essential objective is to provide a valid working simulation model which can display relativities between different operational decisions and resource configurations and which can, with appropriate input, serve to inform broad resource allocation decisions concerning the AVTUR distribution system and its five key elements of demand level, bulk and base storage capacities, transport resources and infrastructure. The model should also be capable of development and enhancement for a variety of purposes.

V. Experimentation

Basic Simulation Design

The AVTUR distribution system is modeled through processes, events and routines which simulate activities at the nominated ports and bases. A block diagram of the simulation model is at Figure 13.

The essential starting processes are the checking of fuel levels at bases and ports. As necessary, these generate calls for resupply (at bases) or restock (at ports) when fuel inventory falls below a specified level. The resupply and restock processes require truck and ship resources respectively. The ship resource is assumed to be available on call but free flow through the system is interrupted if trucks are not available, or if stock at ports is insuffiecient. Such interruptions are modeled by a system generated queue in the case of trucks and by a programmed queue for unsatisfied resupplies.

The time to resupply by land is affected by weather as well as availability of trucks, particularly in the southern summer. Weather is modeled as a random process which, depending on the calender date will inject a rain delay into the resupply process. An arrival process is included to prevent overfilling of base tanks.

Consumption at bases is modeled as a random hourly usage rate related to average daily demand but only after determining whether normal operations can proceed. If they cannot, because the base has reached it reserve level, operations are suspended for the relevant

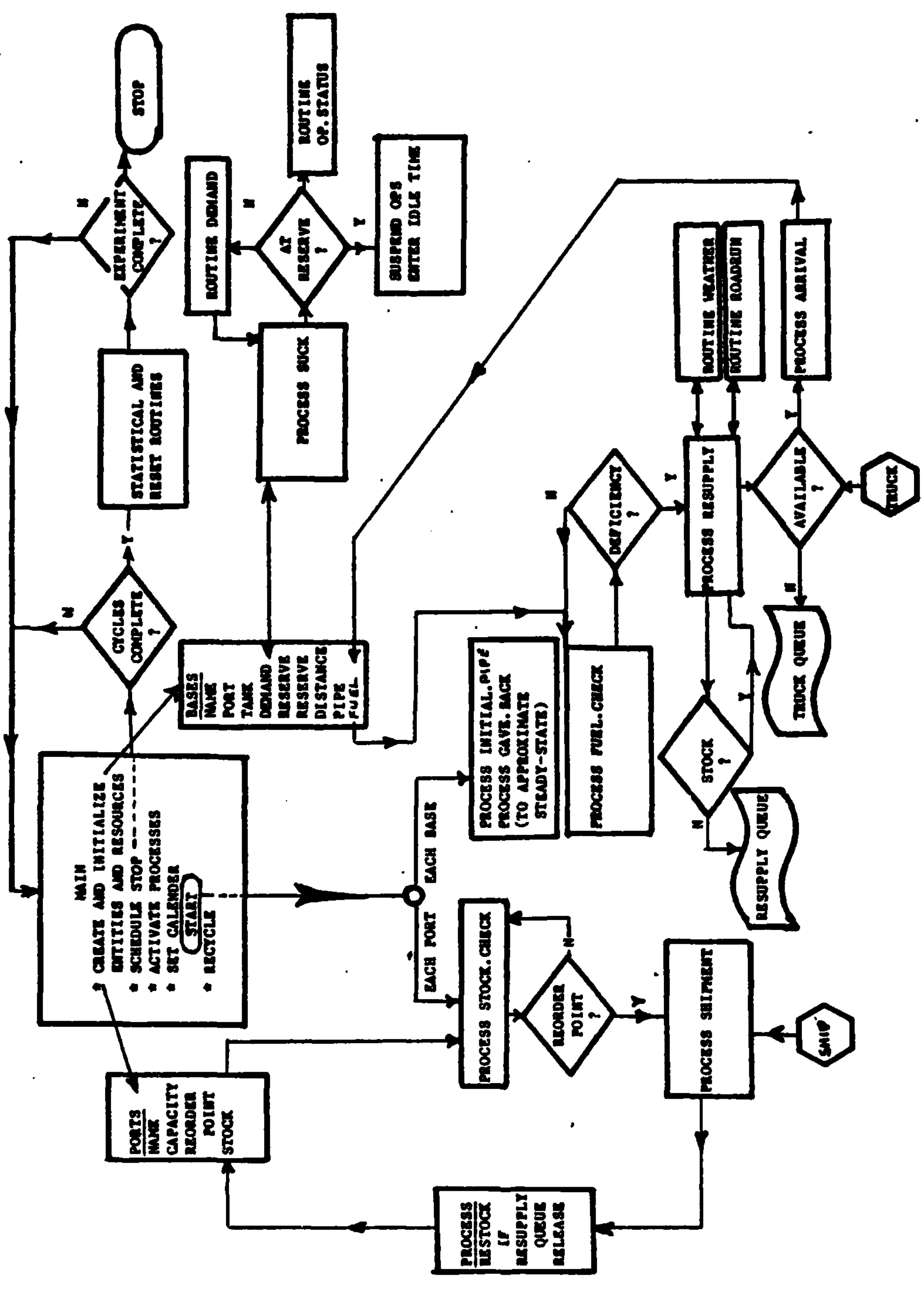


Figure 13. Functional Model of Simulation

base until adequate fuel is available. For each base, the difference between the stopping and restarting of operations (or end of simulation) is accumulated as idle time.

Mean idle time is calculated by SIMCRIPT system routines and summed over all bases at the end of a cycle period of 12 days (related to the time to resupply by ship). Thirty cycles are undertaken for a given truck fleet size. Each cycle is an independent experiment beginning with a different calendar date and different stock/fuel levels, randomly generated to enable later analysis of results using parametric statistical techniques. The thirty point estimates of mean idle time per 12 day period are themselves averaged to provide a point estimate for average idle time during a cycle for given truck fleet size. According to the Central Limit Theorem this estimator should have a normal distribution and associated confidence intervals.

For this initial model the ouput required is a very basic and succinct presentation of "ball park" relativities. The point estimate derived at the end of 30 cycles is therefore presented as a simple graphical representation of the behavior of idle time for different truck fleet sizes and different facilities configurations. To ensure that successive experiments for different truck fleets are comparable, random number generator seeds are saved and restored for each experiment.

The starting values of the variables used in the experiments are listed in Table IV. Since Australian storage capacities are usually specified in megalitres and transport loads in tonnes, an indicative

TABLE IV

Initial Model Input Parameters

(1) Storage Capacities

Location	Bulk Seaboard Storage (tonnes)	Total Airfield Storage (tonnes)
Darwin	19937	2220
Tindal	-	1654
Derby	-	2646
Port Hedland	4551	-
Learmonth	-	1737

(2) Daily Base Demand Rates (Civil Plus Military) and Resupply Distances

	Daily Demand (tonnes)	Distance From Bulk Supply (Kilometres)	
Darwin	230	20	
Tindal	30	354	From Darwin
Derby	350	1717	
Derby	350	768	From Pt. Hedland
Learmonth	350	850	

(3) Resupply Time (Ship)

Assuming one dedicated ship sailing from Perth, filling bulk storage at Port Hedland, Darwin, and Port Hedland again on one resupply cycle, the resupply time (ship) would be 12 days with 3 days sailing time between each berthing. This would need a dedicated tanker with carrying capacity of around 30,000 tonnes. (Feasibility and appropriateness confirmed by Royal Australian Navy sources.)

(4) Resupply Time (Truck)

To be calculated on the basis of a single tanker load of 50 tonnes travelling at an average speed of 40 kilometres per hour between seaboard storage and operational bases for 18 hours every 24 hours where time to resupply exceeds 18 hours, it is calculated as 75% of distance/speed plus time to load from bulk storage at a fill rate of 24 tonnes per hour, and to unload into operational storage at a discharge rate of 60 tonnes per hour. (Flow rates and distances provided by the Australian Department of Defence.)

Source: Various unpublished and unreferenced documents provided by the Australian Department of Defense

conversion factor (extracted from 11:118-119) of 1270 litres per tonne has been used, and quantities/capacities are expressed in tonnes.

A listing of the final computer simulation model developed written in the SIMSCRIPT II.5, simulation language, is attached as Appendix B. SIMSCRIPT is flexible, versatile and "readable" in the sense that variable names and linkages can be constructed which intuitively assist non-specialist understanding of program logic.

In his dissertation on the art of modeling, Morris states as one of three basic hypotheses:

> The process of model development may be usefully viewed as a process of <u>enrichment</u> or <u>elaboration</u>. One begins with very simple models, quite distinct from reality, and attempts to move in evolutionary fashion toward more elaborate models which more nearly reflect the complexity of the actual management situation [20:B-709].

This process of moving from the simple to the complex, involving successive elaboration and testing, was followed closely in the model building procedure. Many models were used, but in essence, they can be summarized into a three step process followed so as to successively approach a reasonable approximation to steady-state behavior.

<u>Initial Model</u>. As a first step, a basic model was constructed which used point estimates for initial values of variables and assigned an obvious superfluity of trucks to each base (100 in each case). To obtain approximate estimates for steady-state parameters, this model was run 50 times and analyzed to provide: (1) estimates of the numbers of dedicated resupply trucks each base would require to eliminate idle time, (2) the average number of trucks which could be expected to be in

transit to and from each base when the system had settled to steady-state, and (3) statistics (mean and standard deviation) to approximate average fuel levels at bases and stock levels at ports.

Interim Model. Using the statistics garnered from the basic model, two processes were constructed to simulate pipeline activity to and from the bases. The program was also changed to assign truck resources to ports rather than bases to allow their more efficient use where one port was serving more than one base. Random sampling for fuel and stock levels, using statistics obtained from the pilot run, and assuming normal distribution was also incorporated into the model. In this, and the final model, the statistics from the total population rather than the mean of means (which would validate the assumption of a normal distribution) were used to retain a larger variance in the distribution and hence a larger potential range of random starting values. In the absence of any empirical data on the actual distribution of tank fuel levels normalcy is assumed. Since such random sampling could produce initial stock levels at a port lower than the port's reorder point, a routine was added to relate the first restock of the first port to the random stock value returned. Demand for each base was also randomized to provide hourly changes in fuel usage during normal operating hours and a probabilistic demand outside those hours.

Final Model. The interim model was run again through 50 cycles to accumulate steady-state estimates for the changed and randomized parameters to maintain idle time at zero. Of these only the last 30 runs were analyzed to overcome any remaining problem of initial transience. The

resultant statistics for fuel distributions, truck assignments to ports, and pipeline insertions were incorporated into thefinal model which appears at Appendix B. Explanations of the choice or deviation for each distribution incorporated into the final model are included in Appendix C.

The internal validity of each computer model was verified by using exhaustive print and list routines which enable manual trace of the model's operation through a twelve day cycle. Calculations were checked by calculator, correct sequencing confirmed, and the operation of random elements such as the weather routine and out-of-hours consumption noted for consistency with the relevant probabilities used.

To assess external or "face" validity, the concept of the simulation was referred to the Chief of Supply in the Australian Department of Defence, Major General A. D. Powell. His general confirmation that the content and the construct of the simulation would provide a useful departure point is attached as Appendix D.

Choice of Experiments

From one calender origin, the final model was constructed to run through thirty successive twelve day cycles, each with different random starting seeds, thus giving coverage for 360 days of the year for any given truck fleet size. Proper comparison between results for different truck fleet sizes was ensured by restarting the simulation with the same sequence of random numbers so as to generate exactly the same starting conditions for the different fleet sizes. For the purpose of the

following discussion, an experiment is defined as the running of the simulation program for thirty twelve day cycles for each nominated truck fleet, while beginning parameters and facilities are held constant.

In this, it must be recalled that the experimental objective is to develop a decision support system - a methodology of informing judgement rather than an actual estimate of what would occur in a given situation. To estimate the effect of the response variable, idle time, to different operational and facilities decisions, three groups of experiments, using different facilities or basing configurations, were constructed.

Operational Decisions. The purpose of the first group of experiments was simply to assess how choice of operational basing might affect the system. In all cases, the facilities configuration (port and base storages) were assumed to remain as they now are, and the values in the basic model were retained.

The model was run once to simulate four operating bases and twice more to exclude Derby as an operational base. Derby was chosen for exclusion for two reasons. Firstly, because of its distance from its resupply port, Darwin, the Derby resupply pipeline is long and vulnerable. Secondly, as the base occupying the middle ground between the operational extremities of Tindal/Darwin in the East and Learmonth in the West, Derby's area of operations could be absorbed more readily from the extremities than could the operation of one extremity by another.

__Port Facilities Decisions__. In the second group of three experiments, bulk seabound storage at Port Hedland was doubled and Derby base resupplied from Port Hedland. Port Hedland is one of the relatively more populous of the northwest towns, and is a centre for economic activity (mainly as a mining port). Although a choice of additional bulk storage at Hedland would not be considered by Defense alone, a civil economic need might attract Defence support.

For the second of this group of experiments, existing bulk storages at Darwin and Port Hedland were held constant, but a bulk storage was constructed at Exmouth, equal in capacity to that at Port Hedland, to supply Learmonth. Exmouth is located close to Learmonth on the Northwest tip of the continent, has some port facilities, and is only two days ship time from the refinery at Perth.

For the third experiment in this group, existing bulk storages were held constant, but a bulk storage equalling Hedland capacity was inserted at Derby to supply that base. For all changes the program was adjusted accordingly to reflect different numbers of ports, base distances, and allocation of truck resources.

__Base Facilities Decisions__. The third group of two experiments was constructed to show the effect of increased base fuel storage on the occurrence of idle time, focussing on Tindal and Learmonth. These two bases with small base fuel facilities, (and a large operational load in the case of Tindal) were the ones most often required to stop

operations. With all other parameters held constant, storage at Tindal was doubled for the first run and storage at Learmonth was doubled for the second.

VI. Findings

General Reservations on Simulation Output

The findings or output of the simulation runs were not subjected to rigorous statistical analysis. The input parameters would need considerably more investigation and precision before it could be claimed with confidence that they reflected real values, and interpretation of the output would rely heavily on the judgement of the interpreter on such basic matters as an acceptable level of idle time in an operational situation or an acceptable level of investment in facilities.

Further, the purpose of this initial research is not to claim infallibility for any particular result, but to demonstrate broad relativities, to inform resource decisions, or to indicate reasonable operational options for given resource configurations.

Nonetheless, statistical analysis was undertaken for one group of experiments to demonstrate what would be required before using the model.

Observations

Operational Decisions. The output from the first group of three experiments is displayed on the graph at Figure 14. This group of experiments assumed that no facilities enhancement would occur before the onset of an emergency.

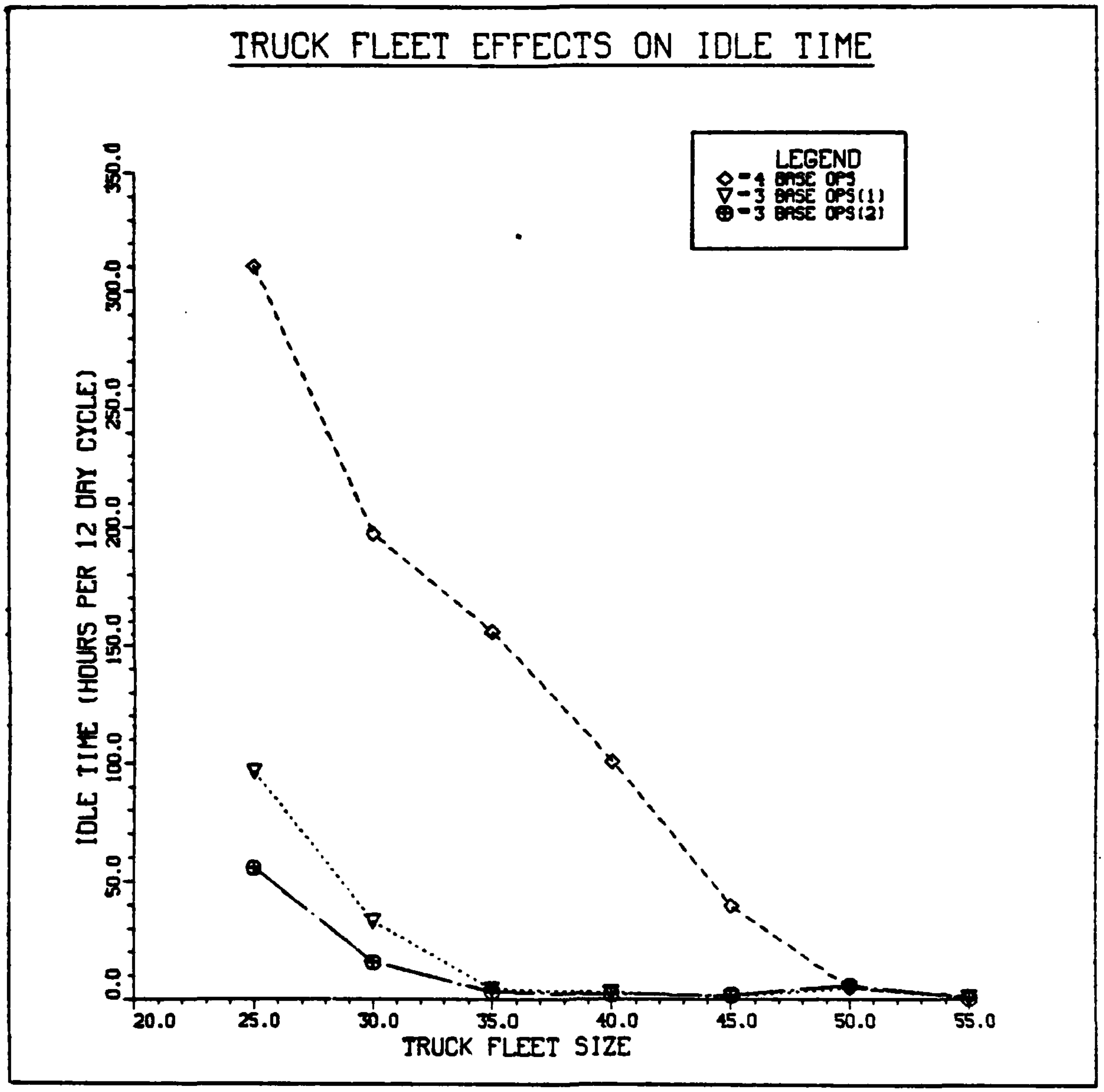


Figure 14. The Effect of Truck Fleet Size on Idle Time for Different Operational Decisions (Base and Port Storages as Now)

To one group of decision-makers, the broad inference of the relativities displayed might be that if no more than 35 tanker trucks were available for use, and the operational criterion is to minimize idle time, then basing at Derby should be discounted as an option. For another group of decision-makers, the inference might be that choice of truck fleet size as between say 25 and 30 trucks for a three base option, should be assessed against the acceptability of one or more bases having restricted operational capability for so many hours in each twelve days.

Bulk Storage Decisions. The results of the second group of experiments, displaying the effect of different added bulk storages, is at Figure 15. All experiments assumed four base operations. Again, the inferences to be drawn from the results depend largely on the choice criteria of the decision-maker.

It might be inferred, for example, that additional bulk storage construction at either Exmouth or Derby was preferable, from a Defense viewpoint, to additional construction at Port Hedland. It might further be inferred that the Exmouth site would provide marginal Defence advantage over Derby. Such inferences could inform negotiations with other Government Departments or with private firms contemplating facilities investment for civil purposes.

As compared with the first group of experiments, other comparisons could be made (and different experiments run). If four base operations and minimization of base idle time were considered essential, the decision-maker might perceive that the cost of building and maintaining

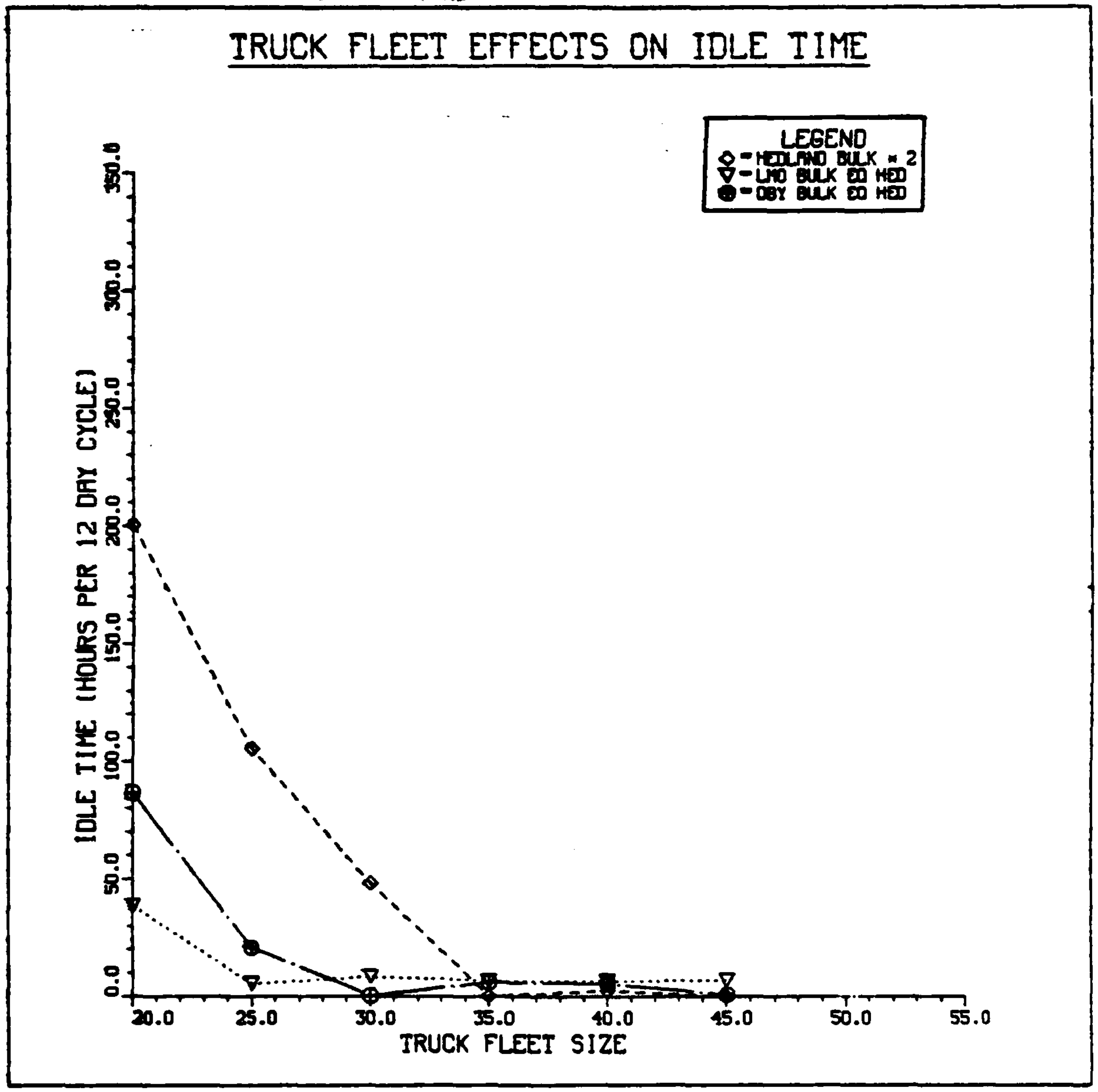


Figure 15. The Effect of Truck Fleet Size on Idle Time for Different Added Bulk Storages

a bulk storage at Exmouth for Defense purposes should be compared with the cost differential between buying/hiring a truck fleet of 50 tankers or 25 tankers. The ramifications are endless.

<u>Statistical Analysis</u>. As an example of the statistical analysis which would be required before presenting simulation results as a basis for decision, the output data for the group of experiments with various bulk storage configurations were was collected (see Appendix E) and confidence intervals were constructed about the point estimates of the system's idle time. These confidence intervals are plotted at Figure 16. The plot demonstrates that from a truck fleet size of 35, there is no statistical significance between the results for any of the three options. For a truck fleet size of 30, there is statistical significance between the results for the first option, but none between the second two. For fleet sizes of 20 to 25, there is statistical significance in the results between all three options.

The simulation also provides a statistical summary at the end of each fleet investigacion. The output for the experiments changing bulk storage facilities - summarized in the graphs at Figures 15 and 16 - is attached as Appendix F.

The output has several uses. Generally, it confirms that the model is behaving "rationally." For small numbers of trucks, truck usage is high and truck queues are relatively long. Standard deviation statistics of fuel distributions are small, as expected from a mean of means calculation. Mean base fuel levels are around the working level

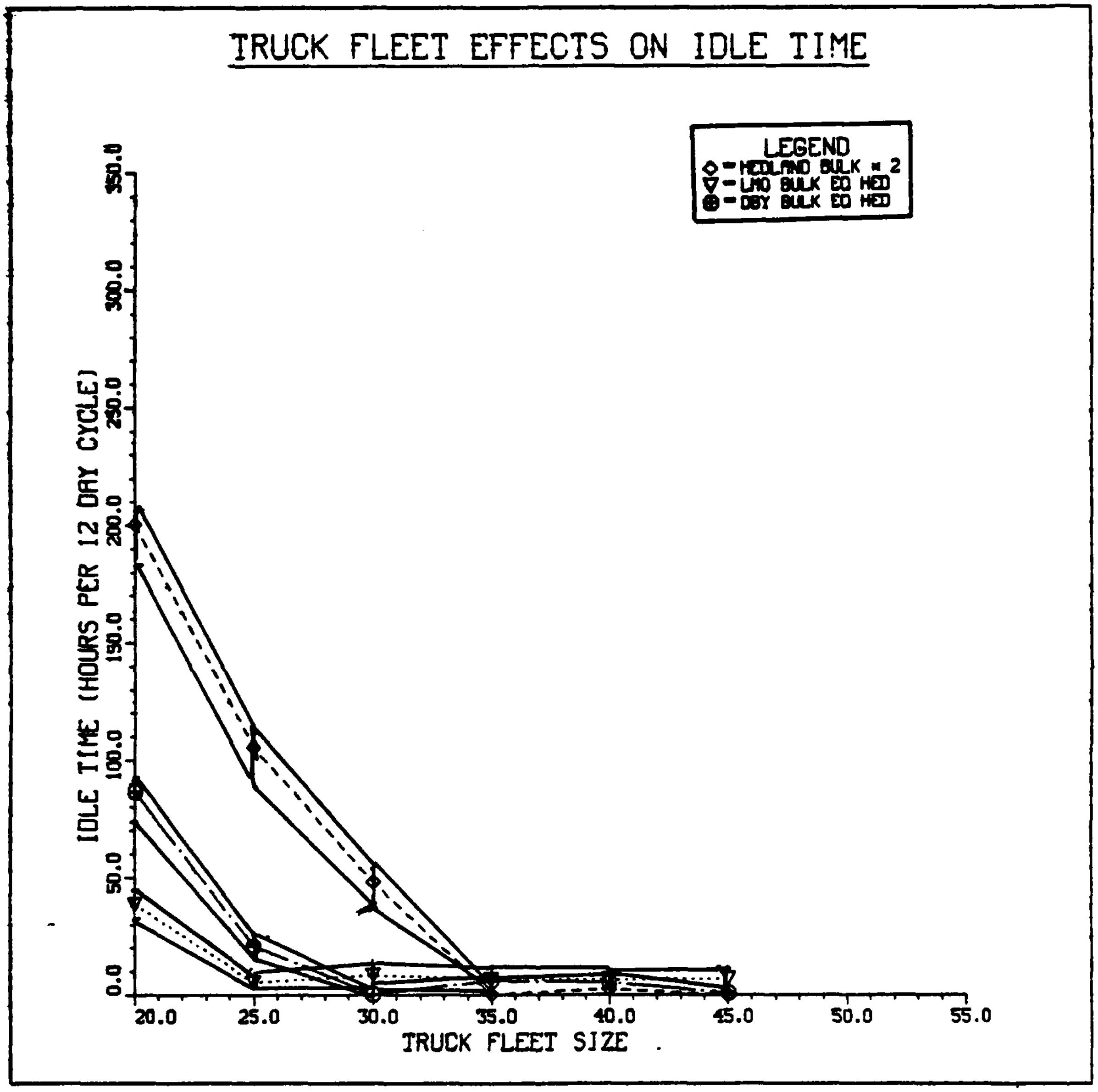


Figure 16. The Effect of Truck Fleet Size on Idle Time for Different Added Bulk Storages (Confidence Intervals Added)

when idle time is zero and significantly lower than the working level when idle time is accumulating at a particular base.

Of interest is the indication that Tindal and Learmonth are usually the major accumulators of idle time. As the numbers of trucks increases, they become the sole accumulators. Intuitively, these are the two bases with small base storage tanks, and causality might be investigated.

For the first of this group of experiments, where bulk storage at Port Hedland is doubled, a comparison of idle time accumulation between Derby and Learmonth - both supplied by Hedland, roughly the same distance from that port and having the same operational demand - shows a significant difference which could be attributed to the disparity between them in base storage capacity.

When additional bulk storage is shifted to Exmouth in the second experiment in the group, the aggregated statistics collected for graphical output should be interpreted against the apparent finding that idle time accumulation at Learmonth is independent of the total truck fleet size. The number of tanker trucks assigned to Exmouth is a constant (2), and the truck use and truck queue statistics are not significantly different for different runs. A truck fleet size of 21, for example, with the additional trucks dedicated to Exmouth, could well reduce idle time significantly, and isolate any effect of base storage capacity.

With Derby as the recipient of additional bulk storage in the third experiment of this group, the difference in system performance which provides the graphical presentation is obviously attributable to

Learmonth's degraded performance. Here, Learmonth is again some distance from its resupply port (in this case, Port Hedland), and when truck resources are scarce, the base soon reaches it reserve fuel levels.

Base Facilities Decisions. The effect of decisions to increase base fuel storage facilities is displayed on the graph at Figure 17. Four bases are assumed to be operating, and for ease of reference the results of the first experiment, with no change to present facilities, is displayed on the same graph.

Again, interpretation requires subjective assumptions about the choice criteria of the decision-maker. It might be inferred for example, that the tradeoff in idle time reduction for building at either Learmonth or Tindal for a truck fleet size of 35 is around 50 hours per twelve day cycle. Alternatively, it might be inferred that to reduce idle time to zero, an additional tank at Tindal would reduce the truck fleet requirement from 50 to 45.

Conclusions

The findings of the experiments are, by design, entirely open to a wide range of interpretations and orientations. What is meaningful to one decision-maker might be irrelevant to another.

What has been demonstrated is that the basic simulation model:

1. Has both internal and face validity.
2. Is relevant to the problems of the higher level decision-maker.

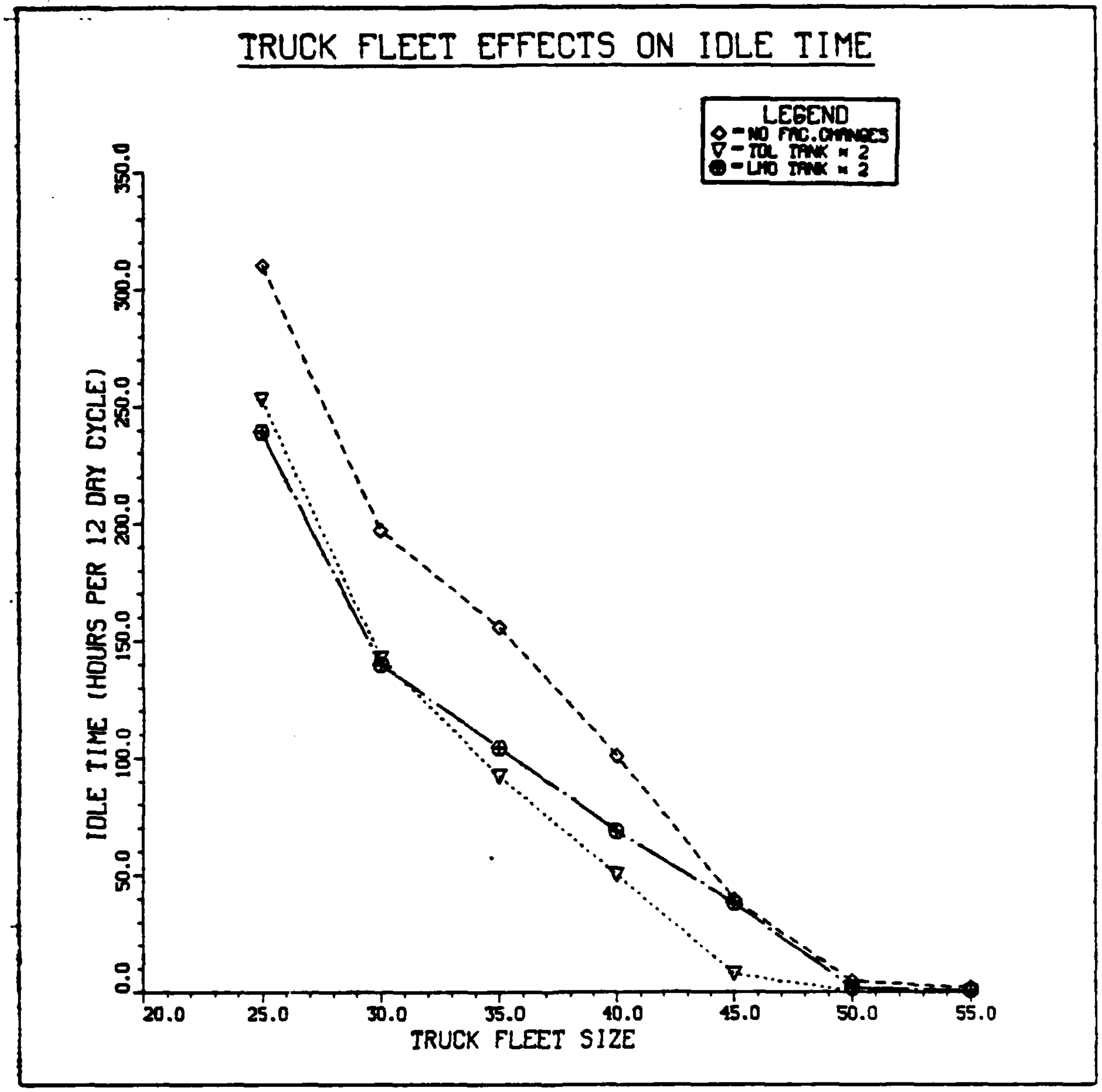


Figure 17. The Effect of Truck Fleet Size on Idle Time for Different Added Base Storages

3. Is usuable and flexible, well capable of responding to "what if" questions when different parameters are input.

4. Could, with refinement, provide a range of information to several levels of interest.

VII. Conclusions and Recommendations

Present Utility of the Simulation Model

What has been developed is an embryo decision support system to inform decisions on the investment of Defence resources in rolling stock (tanker fleets) and fuel storage facilities at Defence bases. The simulation program models what is probably the most critical element of a conceptual AVTUR distribution system, i.e., distribution from bulk storage to base tanks. Even now, with corrected input parameters and validated statistical distributions, the model could be used by Defence decision-makers to imply broad comparisons and tradeoffs between different decisions. It can be broadly assessed whether or not fuel tankers should be included in Defence inventory or whether the numbers required for different levels of effort would be likely to be available from civil resources. Assuming a decision to invest in tankers, it might indicate what is potentially the best mix between on-base storages and numbers of tanker trucks.

Desirable Enhancements

Besides refinement of input, the following enhancements would considerably improve the utility of the model:

1. The ship resupply system should be modeled in detail, by relaxing the assumptions of immediate refinery response, availability of a ship of appropriate size on call, and no interruptions caused by the elements or by hostile activities. One large tanker serving all ports seriatim might not be either cost-effective or operationally desirable.

2. Concomitantly, redundant systems should be modeled, e.g., the use of several smaller ships or replacement of bulk sea supply by overland road train from Perth and/or Adelaide refineries.

3. Actual pipelines should be selectively modeled as substitutes for truck resupply or as redundant systems. Particularly in the case of Tindal, with a heavy operating demand and small base facilities, pipeline construction might be a reasonable proposition as an alternative to both truck fleets and new tank construction.

4. Once the system model was completed for a single fuel, AVTUR, it could be enlarged to embrace other operational fuels.

5. At all levels of complexity, iterative terminal input should be introduced as an option to internal program assignment of variables. The task is not difficult, and an example of an iterative routine which provided this facility on one of the earlier simulation models is attached as Appendix G. Iterative terminal input would put control of parameters directly into the hands of the decision-makers and provide full flexibility responsive to individual interests.

Potential Utility

An enhanced simulation model would provide bettter answers to purely Defence questions, but its utility would not stop there. In the partitioning of responsibilities between Government Departments, an overlapping or common interest can be subjected to extremes of intense rivalry or denial of any responsibility whatsoever. But between those extremes much time and effort is dedicated to problems of coordination and influence, with or without committment.

An enhanced model could be used to better define and quantify Defence interests in such matters as the building of additional civil bulk storage facilities. Decisions on such matters are left largely to commercial interests, but there are broad Government policies and regulations which look beyond the profit motive to the need for spare storage capacities to ameliorate the effects of sudden demand surges or supply disruptions. Defence interests constitute an element of that larger national interest, and any reasonable quantification of the Defence interest could present useful opportunities to exert influence.

Quantification of Defence interests could also contribute to national decisions on such matters as the allocation of resources to Northwestern highway maintenance and extension, the expansion of rail networks or the building of new refineries. There is a real defence interest in these decisions but the interest relates to hypothetical contingencies to which are attached very low probabilities of occurrence. If the hypothetical resource needs can be broadly quantified, so too can the necessary inclusion in the standing Defence Force to provide a proper basis for expansion in time of need.

Completion of a north-south railway link across the continent from Adelaide to Darwin has been comteplated by various Governments over the years. Defence needs for aviation fuel in a contingency situation would obviously not decide the matter. Nor, necessarily, would full quantification of Defence logistic needs. But such quantification could contribute usefully to the debate and perhaps have some influence on the outcome.

A decision on whether, and if so, where, to build a refinery in the Northern Territory (in which Darwin is located) could be influenced by a reasonable appreciation of the likely effect on Defence resource requirements in a contingency. Referring back to Figure 8, the oil discovery at Mermeenie, near Alice Springs in the centre of Australia, is expected to begin production of around 64,000 tonnes of crude oil this year, and production could increase to some 200,000 tonnes/year within the decade. An oil refinery at Darwin is being considered to refine crude oil from the nearby Bonaparte gulf fields (see Figure 8).

Again, it is obvious that such decisions would not be made on Defence interests alone. But in a finely balanced decision situation, the Defence interest might be enough to tip the scales in the right direction. If that interest can be quantified, it becomes considerably more cogent.

Internationally, there might be a United States interest in leasing bulk aviation fuel storage facilities on the West Coast of Australia to simplify fuel supply for surveillance forces deployed into or transiting the Indian Ocean. Such facilities are presently either very limited or non-existent, but if their existence could be demonstrated to considerably enhance Australia's national defensive capabilities, a policy of building Defence facilities for initial lease might bear investigation.

Conclusion

The model developed in this research is one of limited present performance. It does, as intended, create the potential for a decision support system capable of demonstrating broad relationships between

some decision variables relevant to the distribution of AVTUR in North West Australia. With the enhancements suggested above, it could have considerably more future potential.

However, such efforts can never be regarded as fully complete. To quote from an article which has become a classic reference on the art of modeling:

> Skill in modeling certainly involves a sensitive and selective perception of management situations. This, in turn, depends on the sort of conceptual structures one has available with which to bring some order out of the perceptual confusion. Models can play the role of giving structure to experience. Yet we seldom encounter a model which is already available in fully satisfactory form for a given management situation, and the need for creative development or modification is almost universally experienced in management science [20:B-708].

Appendix A: IDEF Methodology

The ICAM Definition Method (IDEF) starts by representing the whole system as a single modular unit--a box with arrow interfaces. Since the single box represents the system as a whole, the descriptive name written in the box must be general, rather abstract, and lacking in detail. The same is true of the interface arrows, since they also represent the complete set of external interfaces to the system as a whole.

The box that represents the system as a single module is then detailed on another diagram with several boxes connected by interface arrows. These interconnections make the boxes represent major submodules of the single parent module. The decomposition reveals a complete set of submodules, each represented as a box whose boundaries are defined by the interface arrows. Each of these submodule boxes may be similarly decomposed to expose even more detail.

IDEF provides rules covering how to gradually introduce further detail during decomposition. A module is always divided into no fewer than three, but no more than six submodules. The upper limit of six forces the use of a hierarchy to describe complex subjects. The lower limit of three was chosen to insure that enough detail is introduced to make the decomposition of interest.

Each diagram in a model is shown in precise relationship to other diagrams by means of interconnecting arrows. When a module is decomposed to submodules, the interfaces between the submodules are

shown as arrows. The name of each submodule box plus its labeled interfaces define a bounded context for detailing of that submodule.

In all cases, every submodule is restricted to contain only those elements that lie within the scope of its parent module. Further, the module cannot omit any elements. Thus, as already indicated, the parent box and its interfaces provide a context. Nothing added or removed from this precise boundary [32:2-5].

Appendix B: Simulation Program

```
''    ##################################################
''    # AVTUR DISTRIBUTION SYSTEM FOR NORTHWEST AUSTRALIA #
''    ##################################################

''     (( NOTE REFERENCES ARE TO THE NOTES IN APPENDIX C ))


PREAMBLE
  NORMALLY MODE IS INTEGER
  PERMANENT ENTITIES
     EVERY PORT HAS A PT.NAME,
                   A PT.CAPACITY,    ''BULK STORAGE AT PORT
                   A PT.STOCK,       ''BULK FUEL INVENTORY
                   A PT.STCK.POSN,   ''ABLE TO FILL ORDERS
                   A PT.DRAIN,       ''DAILY DEMAND
                   A PT.REORDER.PT,  ''REORDER LEVEL AT PORT
                   A MU.STOCK,       ''MEAN OVER 12 DAYS
                   A MU.Q.TRUCK,     ''MEAN QUEUE(12 DAYS)
                   A MU.U.TRUCK      ''RERCENT UTILIZATION
     EVERY BASE HAS A BA.NAME,
                   A BA.PORT,        ''PORT SUPPLYING BASE
                   A BA.TANK,        ''BASE STORAGE CAPACITY
                   A BA.FUEL,        ''BASE FUEL STOCK LEVEL
                   A BA.DEMAND,      ''AVERAGE DAILY DEMAND
                   A BA.HOURLY.USE,  ''HOURLY USAGE RATE
                   A BA.DISTANCE,    ''ROAD DISTANCE TO PORT
                   A BA.RESERVE,     ''EMERGENCY RESERVE
                   A BA.ORDER,       ''ALL TRUCKS TO & FROM
                   A BA.SUP.DELAY,   ''IF PORT STOCK IS LOW
                   A BA.TRUCK.DELAY,''NO TRUCK AVAILABLE
                   A BA.PIPELINE,    ''FULL TRUCKS ENROUTE
                   A BA.AVAIL.FUEL,  ''STOCK MINUS RESERVE
                   A BA.STOP.TM,     ''IF AT RESERVE
                   A BA.BEGIN.TM,    ''RESTART AFTER IDLE
                   A BA.IDLE.TIME,   ''EMERGENCY ONLY
                   A MU.FUEL,        ''MEAN OVER 12 DAYS
                   A MU.IDLE
  RESOURCES INCLUDE SHIP,
                    TRUCK
  PROCESSES
     INCLUDE SHIPMENT                ''FROM REFINERY TO PORT
     EVERY RESUPPLY HAS A SHORTAGE   ''DISTRIBUTE PORT-BASE
        AND MAY BELONG TO THE QUEUE
```

```
   EVERY FUEL.CHECK HAS A FARM     ''CHECK ON BASE FUEL
   EVERY STOCK.CHECK HAS A DEPOT   ''CHECKS FUEL AT PORT
   EVERY RESTOCK HAS A RS.DEPOT    ''RESTOCK PORT EX SHIP
   EVERY SUCK HAS A DEBIT          ''BASE FUEL CONSUMPTION
   EVERY INITIAL.PIPE HAS A RECIPIENT ''STARTING PIPELINE
   EVERY GIVE.BACK HAS A DONOR        ''RETURN PIPELINE
   EVERY ARRIVAL HAS A GRATEFUL.CO    ''UNLOAD AT BASE
   EVERY REJOIN.POOL HAS A DUTY.DONE  ''TRUCK RETURN
THE SYSTEM OWNS THE QUEUE

EVENT NOTICES
   INCLUDE CLEAR.PORTS

DEFINE BA.FUEL,BA.STOP.TM,BA.BEGIN.TM AS REAL VARIABLES
DEFINE TOT.IDOL,AV.IDOL AS REAL VARIABLES
DEFINE END.OF.SIM, BA.IDLE.TIME,IDOL.TM AS REAL VARIABLES
DEFINE PT.STOCK,BA.RESERVE,BA.AVAIL.FUEL AS REAL VARIABLES
DEFINE MU.STOCK,MU.Q.TRUCK,MU.U.TRUCK AS REAL VARIABLES
DEFINE MU.FUEL, MU.IDLE AS REAL VARIABLES
DEFINE FLYING AND NO.OF.CYCLES AS INTEGER VARIABLES
DEFINE FLEET.OF.TRUCKS AS AN INTEGER VARIABLE
DEFINE MN.STOCK AND MN.FUEL AS REAL VARIABLES
DEFINE BEGIN.DATE AS A ROUTINE YIELDING 2 ARGUMENTS
DEFINE  PT.DRAIN, START.TIME AS REAL VARIABLES
DEFINE DUES.IN AS A ROUTINE YIELDING 1 ARGUMENT
DEFINE OUT.COUNT AND IN.COUNT AS INTEGER VARIABLES
DEFINE WEATHER AS A ROUTINE GIVEN 1 ARGUMENT YIELDING
                                          1 ARGUMENT
DEFINE ROADRUN AS A ROUTINE GIVEN 1 ARGUMENT YIELDING
                                          1 ARGUMENT
DEFINE DEMAND AS A ROUTINE GIVEN 1 ARGUMENT YIELDING
                                         1 ARGUMENT
DEFINE OP.STATUS AS A ROUTINE GIVEN 1 ARGUMENT YIELDING
                                            1 ARGUMENT
DEFINE PT.NAME,
       BA.NAME,
       BA.PORT AS TEXT VARIABLES
DEFINE FLAG TO MEAN 1
DEFINE DARWIN TO MEAN 1
DEFINE HEDLAND TO MEAN 2
DEFINE DWN TO MEAN 1
DEFINE TDL TO MEAN 2
DEFINE DBY TO MEAN 3
DEFINE LMO TO MEAN 4
DEFINE ADEQUATE TO MEAN 0
DEFINE INADEQUATE TO MEAN 1
DEFINE NO.GO TO MEAN 0
DEFINE GO.GO TO MEAN 1
ACCUMULATE AV.PIPE AS THE MEAN,         ''TO COLLECT STATS
           SD.PIPE AS THE STD.DEV,      ''ON TRUCK TRAFFIC
           MAX.PIPE AS THE MAXIMUM,     ''FOR EACH BASE
```

```
    AND MIN.PIPE AS THE MINIMUM OF BA.ORDER
 ACCUMULATE AV.STOCK AS THE MEAN,           ''TO COLLECT STATS
    AND SD.STOCK AS THE STD.DEV OF PT.STOCK  '' ON PORT STOCK
 ACCUMULATE AV.FUEL AS THE MEAN,            ''TO COLLECT STATS
            SD.FUEL AS THE STD.DEV,         ''ON FUEL LEVEL
            MAX.FUEL AS THE MAXIMUM,        ''FOR EACH BASE
        AND MIN.FUEL AS THE MINIMUM OF BA.FUEL
 ACCUMULATE AV.QUEUE AS THE MEAN,
            SD.QUEUE AS THE STD.DEV OF N.Q.TRUCK
 ACCUMULATE AV.USED AS THE MEAN,
            SD.USED AS THE STD.DEV OF N.X.TRUCK
 TALLY MOM.STCK AS THE MEAN
    AND SSD.STCK AS THE STD.DEV OF MU.STOCK
 TALLY MOM.FUEL AS THE MEAN
    AND SSD.FUEL AS THE STD.DEV OF MU.FUEL
 TALLY MOM.Q AS THE MEAN,
    SSD.Q AS THE STD.DEV OF MU.Q.TRUCK
 TALLY MOM.USED AS THE MEAN,
    SSD.USED AS THE STD.DEV OF MU.U.TRUCK
 TALLY MN.IDLE AS THE MEAN,
    VAR.IDLE AS THE STD.DEV OF MU.IDLE
END ''^^^^^^^^^^^^^^^^^^^^^^^ PREAMBLE ^^^^^^^^^^^^^^^^^^^^^^^^
```

```
MAIN
DEFINE CYCLES AS AN INTEGER VARIABLE
DEFINE FIRST.STOCK AS A REAL VARIABLE
DEFINE SAVESEED1,SAVESEED2,SAVESEED3,SAVESEED4,SAVESEED5,
        SAVESEED6,SAVESEED7,SAVESEED9 AS INTEGER VARIABLES
LET SAVESEED1 = SEED.V(1)
LET SAVESEED2 = SEED.V(2)
LET SAVESEED3 = SEED.V(3)
LET SAVESEED4 = SEED.V(4)          ''# NOTE 1
LET SAVESEED5 = SEED.V(5)
LET SAVESEED6 = SEED.V(6)
LET SAVESEED7 = SEED.V(7)
LET SAVESEED9 = SEED.V(9)
LET NO.OF.CYCLES = 30
CALL BEGIN.DATE YIELDING MM,DD
CALL ORIGIN.R(MM,DD,84)
SKIP 2 LINES
FOR FLEET.OF.TRUCKS = 25 TO 55 BY 5
  DO
    LET TIME.V = 0.0
    LET END.OF.SIM = 0.0
    LET SEED.V(1) = SAVESEED1
    LET SEED.V(2) = SAVESEED2
    LET SEED.V(3) = SAVESEED3
    LET SEED.V(4) = SAVESEED4      ''# NOTE 1
    LET SEED.V(5) = SAVESEED5
    LET SEED.V(6) = SAVESEED6
    LET SEED.V(7) = SAVESEED7
    LET SEED.V(9) = SAVESEED9
    CREATE EVERY TRUCK(2)
    LET U.TRUCK(DARWIN) = INT.F(0.74*FLEET.OF.TRUCKS)  ''# NOTE 2
    LET U.TRUCK(HEDLAND) = INT.F(0.26*FLEET.OF.TRUCKS)
    FOR CYCLES = 1 TO NO.OF.CYCLES
      DO
        LET START.TIME = TIME.V
        LET IDOL.TM = 0
        ADD 12 TO END.OF.SIM            ''# NOTE 3
        CALL ASSINFO
        CALL DUES.IN YIELDING FIRST.STOCK
        FOR EACH BASE
           ACTIVATE AN INITIAL.PIPE GIVING BASE NOW
        FOR EACH BASE
           ACTIVATE A GIVE.BACK GIVING BASE NOW
        FOR EACH BASE
           ACTIVATE A FUEL.CHECK GIVING BASE IN 2 MINUTES
        FOR EACH PORT
           ACTIVATE A STOCK.CHECK GIVING PORT IN 2 MINUTES
        FOR EACH BASE
           ACTIVATE A SUCK GIVING BASE IN 2 MINUTES
        SCHEDULE A CLEAR.PORTS IN 12 DAYS
```

```
        START SIMULATION

        CALL STOP.SIM
      LOOP
       LET AV.IDOL = TOT.IDOL/NO.OF.CYCLES
        WRITE FLEET.OF.TRUCKS,AV.IDOL AS 2 D(12,4),/ USING
                                         UNIT 43
        CALL SUM.STATS
        RESET TOTALS OF MU.STOCK,MU.Q.TRUCK,MU.U.TRUCK,
                        MU.FUEL,MU.IDLE
        FOR EACH PORT
          DO
            LET MU.STOCK = 0
            LET MU.Q.TRUCK = 0
            LET MU.U.TRUCK = 0
          LOOP
        FOR EACH BASE
          DO
            LET MU.FUEL = 0
            LET MU.IDLE = 0
          LOOP
    LOOP
END ''^^^^^^^^^^^^^^^^^^^^^^^^ MAIN ^^^^^^^^^^^^^^^^^^^^^^^^^^^
```

```
ROUTINE BEGIN.DATE YIELDING MM AND DD         ''# NOTE 4
  DEFINE MM AND DD AS INTEGER VARIABLES
  LET DD = RANDI.F(1,28,1)
  LET MM = RANDI.F(1,12,2)
  RETURN WITH MM
  RETURN WITH DD
END ''^^^^^^^^^^^^^^^^^^ ROUTINE BEGIN.DATE ^^^^^^^^^^^^^^^^^^
```

```
ROUTINE DUES.IN YIELDING FIRST.STOCK           ''# NOTE 5
  DEFINE FIRST.STOCK AS A REAL VARIABLE
  DEFINE DIF.DAR AND DIF.HED AS REAL VARIABLES
  DEFINE ARREARS AND LAPSE AS REAL VARIABLES
  LET DIF.DAR = PT.STOCK(DARWIN) - PT.REORDER.PT(DARWIN)
  LET DIF.HED = PT.STOCK(HEDLAND) - PT.REORDER.PT(HEDLAND)
  LET ARREARS = DIF.DAR/PT.DRAIN(DARWIN)
  LET LAPSE = DIF.HED/PT.DRAIN(HEDLAND)
  IF ((ARREARS LT 0.0) AND (ABS.F(ARREARS) GT 3.0)) OR
        ((LAPSE LT 0.0) AND (ABS.F(LAPSE) GT 3.0))
     LET FIRST.STOCK = 0.042          ''ONE HOUR
  ALWAYS
  IF (ARREARS LT 0.0) AND (LAPSE LT 0.0)
     IF LAPSE GT ARREARS
        LET FIRST.STOCK = ABS.F(ARREARS)
     ELSE
       LET FIRST.STOCK = ABS.F(LAPSE)
     ALWAYS
  ALWAYS
  IF (ARREARS LT 0.0) AND (LAPSE >= 0.0)
     LET FIRST.STOCK = ABS.F(ARREARS)
  ALWAYS
  IF (ARREARS >= 0.0) AND (LAPSE LT 0.0)
     LET FIRST.STOCK = ABS.F(LAPSE)
  ALWAYS
  IF (ARREARS >= 0.0) AND (LAPSE >= 0.0)
     LET FIRST.STOCK = 3.0
  ALWAYS
  RETURN WITH FIRST.STOCK
END ''^^^^^^^^^^^^^^^^^^^ ROUTINE DUES.IN ^^^^^^^^^^^^^^^^^^^
```

```
PROCESS INITIAL.PIPE(RECIPIENT)   ''TO APPROXIMATE STEADY STATE
  DEFINE RECIPIENT AND SOURCE AS INTEGER VARIABLES    ''# NOTE 6
  DEFINE INCOMING, I AND J AS RECURSIVE INTEGER VARIABLES
  DEFINE PIPE.TM AND STAGGER AS RECURSIVE REAL VARIABLES
  DEFINE BACK.TM AS A REAL VARIABLE
  LET BACK.TM = BA.DISTANCE(RECIPIENT)/60
  LET INCOMING = BA.PIPELINE(RECIPIENT)
  CALL ROADRUN GIVING RECIPIENT YIELDING PIPE.TM
  LET STAGGER = PIPE.TM/INCOMING

  IF RECIPIENT LT 4
     LET SOURCE = DARWIN
  OTHERWISE
     LET SOURCE = HEDLAND
  ALWAYS

  IF INCOMING NE 0
    FOR I = 1 TO INCOMING
    DO
      REQUEST 1 TRUCK(SOURCE)
      IF (END.OF.SIM - TIME.V)*24 GT STAGGER*I
         ACTIVATE AN ARRIVAL GIVING RECIPIENT IN
                                   (STAGGER*I) HOURS
      ALWAYS
      IF (END.OF.SIM - TIME.V)*24 GT (STAGGER*I+BACK.TM)
         ACTIVATE A REJOIN.POOL GIVING RECIPIENT IN
                            (STAGGER*I + BACK.TM) HOURS
      ALWAYS
    LOOP
  ALWAYS
  IF INCOMING NE 0
     WAIT (STAGGER + BACK.TM) HOURS
     RELINQUISH 1 TRUCK(SOURCE)
        FOR J = 2 TO INCOMING
        DO
          WAIT STAGGER HOURS
          RELINQUISH 1 TRUCK(SOURCE)
        LOOP
  ALWAYS
  RETURN
END ''^^^^^^^^^^^^^^^^^ PROCESS INITIAL.PIPE ^^^^^^^^^^^^^^^^^
```

```
PROCESS GIVE.BACK(DONOR)                              ''# NOTE 7
  DEFINE DONOR AND RETURNING AS INTEGER VARIABLES
  DEFINE K AND L AS RECURSIVE INTEGER VARIABLES
  DEFINE BAK AS A REAL VARIABLE
  LET BAK = BA.DISTANCE(DONOR)/60
  LET RETURNING = BA.ORDER(DONOR) - BA.PIPELINE(DONOR)

  IF DONOR < 4
     LET DEST = DARWIN
  OTHERWISE
     LET DEST = HEDLAND
  ALWAYS

  IF RETURNING NE 0
     FOR L = 1 TO RETURNING
     DO
      REQUEST 1 TRUCK(DEST)
       IF (END.OF.SIM - TIME.V)*24 GT (L*BAK/RETURNING)
         ACTIVATE A REJOIN.POOL(DONOR) IN L*BAK/RETURNING HOURS
       ALWAYS
     LOOP
  ALWAYS

  IF RETURNING NE 0
     FOR K = 1 TO RETURNING
     DO
       WAIT (BAK/RETURNING) HOURS
       RELINQUISH 1 TRUCK(DEST)
     LOOP
  ALWAYS

  RETURN
END ''^^^^^^^^^^^^^^^^^^^ PROCESS GIVE.BACK ^^^^^^^^^^^^^^^^^^^
```

```
PROCESS ARRIVAL(GRATEFUL.CO)                      ''# NOTE 8
  DEFINE GRATEFUL.CO AS AN INTEGER VARIABLE
  DEFINE ROOM AS A RECURSIVE REAL VARIABLE
  'UNLOAD'LET ROOM = BA.TANK(GRATEFUL.CO)-BA.FUEL(GRATEFUL.CO)
          IF ROOM GT 50
            ADD 50 TO BA.FUEL(GRATEFUL.CO)
          OTHERWISE
            IF (END.OF.SIM - TIME.V)*1440 GT 30
               WAIT 30 MINUTES
               GO TO 'UNLOAD'
            OTHERWISE
               RETURN
          ALWAYS
  SUBTRACT 1 FROM BA.PIPELINE(GRATEFUL.CO)
  RETURN
END ''^^^^^^^^^^^^^^^^ PROCESS ARRIVAL ^^^^^^^^^^^^^^^^^^^^^^^^
```

```
PROCESS REJOIN.POOL(DUTY.DONE)
  SUBTRACT 1 FROM BA.ORDER(DUTY.DONE)
  ADD 1 TO IN.COUNT
  RETURN
END ''^^^^^^^^^^^^^ PROCESS REJOIN.POOL ^^^^^^^^^^^^^^^^^^^^^^^
```

```
PROCESS SHIPMENT                                         ''# NOTE 9
  REQUEST 1 SHIP(1)
  LET FLYING = FLAG
  IF (END.OF.SIM - TIME.V) GT FIRST.STOCK
     WORK FIRST.STOCK DAYS
     ACTIVATE A RESTOCK GIVING HEDLAND NOW
  OTHERWISE
     JUMP AHEAD
  ALWAYS
  IF (END.OF.SIM - TIME.V) GT 3.000
     WORK 3 DAYS
     ACTIVATE A RESTOCK GIVING DARWIN NOW
  OTHERWISE
     JUMP AHEAD
  ALWAYS
  IF (END.OF.SIM - TIME.V) GT 3.000
     WORK 3 DAYS
     ACTIVATE A RESTOCK GIVING HEDLAND NOW
  OTHERWISE
     JUMP AHEAD
  ALWAYS
  IF (END.OF.SIM - TIME.V) GT 3.0
     WORK 3 DAYS
     RELINQUISH 1 SHIP(1)
     LET FLYING = 0
     RETURN
  ALWAYS
  HERE
  IF (END.OF.SIM - TIME.V) GT 0.0
     WORK END.OF.SIM - TIME.V DAYS
     RELINQUISH 1 SHIP(1)
     LET FLYING = 0
     RETURN
  ALWAYS
END ''^^^^^^^^^^^^^^^^^^^ PROCESS SHIPMENT ^^^^^^^^^^^^^^^^^^^
```

```
PROCESS RESTOCK GIVEN RS.DEPOT                    ''# NOTE 10
  DEFINE RS.DEPOT AS AN INTEGER VARIABLE
  DEFINE I AS AN INTEGER VARIABLE
  LET PT.STOCK(RS.DEPOT) = PT.CAPACITY(RS.DEPOT)
  IF PT.STCK.POSN(RS.DEPOT) EQ INADEQUATE
     FOR EACH BASE WITH BA.PORT(BASE) EQ PT.NAME(RS.DEPOT)
     DO
       IF BA.SUP.DELAY(BASE) NE 0
        FOR I = 1 TO BA.SUP.DELAY(BASE)
        DO
           REMOVE THE FIRST RESUPPLY FROM QUEUE
           IF (END.OF.SIM - TIME.V) GT 0.000
              ACTIVATE A RESUPPLY GIVING BASE NOW
           ELSE
              CANCEL RESUPPLY
           ALWAYS
        LOOP
        LET BA.SUP.DELAY(BASE) = 0
       ALWAYS
     LOOP
     LET PT.STCK.POSN(RS.DEPOT) = ADEQUATE
  ALWAYS
  RETURN
END ''^^^^^^^^^^^^^^^^^^ ^ PROCESS RESTOCK ^^^^^^^^^^^^^^^^^^^^^
```

```
PROCESS RESUPPLY GIVEN SHORTAGE               ''# NOTE 11
  DEFINE SHORTAGE AS AN INTEGER VARIABLE
  DEFINE MONTH,RAIN.DELAY AS RECURSIVE INTEGER VARIABLES
  DEFINE TRANSTIME,ARR.TM,TOT.TM AND R AS REAL VARIABLES
  DEFINE SOURCE AS A RECURSIVE INTEGER VARIABLE
  DEFINE DAZE.BACK AS A RECURSIVE REAL VARIABLE
  LET DAZE.BACK = BA.DISTANCE(SHORTAGE)/1440  ''# NOTE 12
  IF SHORTAGE < 4
     LET SOURCE = DARWIN
  ELSE
     LET SOURCE = HEDLAND
  ALWAYS
  HERE
  IF PT.STOCK(SOURCE) LT 50
     LET PT.STCK.POSN(SOURCE) = INADEQUATE
     FILE RESUPPLY IN QUEUE
     ADD 1 TO BA.SUP.DELAY(SHORTAGE)
     SUSPEND
     RETURN
  ALWAYS
  ADD 1 TO BA.TRUCK.DELAY(SHORTAGE)
  REQUEST 1 TRUCK(SOURCE)
  SUBTRACT 1 FROM BA.TRUCK.DELAY(SHORTAGE)
  IF PT.STCK.POSN(SOURCE) EQ INADEQUATE
     RELINQUISH 1 TRUCK(SOURCE)
     JUMP BACK
  ALWAYS
  IF TIME.V GT END.OF.SIM
     JUMP AHEAD
  ALWAYS
  ADD 1 TO BA.PIPELINE(SHORTAGE)
  ADD 1 TO BA.ORDER(SHORTAGE)
  ADD 1 TO OUT.COUNT


  IF PT.STOCK(SOURCE) GT 50.0
     SUBTRACT 50.0 FROM PT.STOCK(SOURCE)
     IF FLAG NE FLYING AND (END.OF.SIM - TIME.V) GT 0.0
       ACTIVATE A STOCK.CHECK GIVING SOURCE NOW
     ALWAYS
  OTHERWISE
     RELINQUISH 1 TRUCK(SOURCE)
     JUMP BACK
  ALWAYS
  LET MONTH = MONTH.F(TIME.V)
  IF SHORTAGE = DBY OR SHORTAGE = LMO
     CALL WEATHER GIVING MONTH YIELDING RAIN.DELAY ''# NOTE 13
     THEN IF RAIN.DELAY > 0
        LET R = LOG.NORMAL.F(1.0,0.5,7)
  ALWAYS
```

```
   CALL ROADRUN GIVING SHORTAGE YIELDING TRANSTIME  ''# NOTE 14
   LET TOT.TM = R + TRANSTIME/24
   LET ARR.TM = TIME.V + TOT.TM
   IF (END.OF.SIM - TIME.V) GT TOT.TM
      WORK TOT.TM DAYS
   OTHERWISE
      WORK (END.OF.SIM - TIME.V) DAYS
   ALWAYS
   IF TIME.V GT END.OF.SIM
      SUBTRACT 1 FROM BA.PIPELINE
      SUBTRACT 1 FROM BA.ORDER
      JUMP AHEAD
   ALWAYS
   IF (END.OF.SIM - TIME.V) GT 0.000
      ACTIVATE AN ARRIVAL(SHORTAGE) NOW
   ALWAYS
   IF (END.OF.SIM - TIME.V) GT DAZE.BACK
      WORK DAZE.BACK DAYS                ''# NOTE 12
   OTHERWISE
      WORK (END.OF.SIM - TIME.V) DAYS
   ALWAYS
   IF TIME.V GT END.OF.SIM
       SUBTRACT 1 FROM BA.ORDER
      JUMP AHEAD
   ALWAYS
   IF (END.OF.SIM - TIME.V) GT 0.000
      ACTIVATE A REJOIN.POOL(SHORTAGE) NOW
   ALWAYS
   RELINQUISH 1 TRUCK(SOURCE)
   HERE
   RETURN
END ''^^^^^^^^^^^^^^^^^^^^ PROCESS RESUPPLY ^^^^^^^^^^^^^^^^^^^^
```

```
ROUTINE WEATHER GIVEN MONTH YIELDING RAIN       ''# NOTE 15

  DEFINE MTH AND RAIN AS RECURSIVE INTEGER VARIABLES
  DEFINE X AS A RECURSIVE REAL VARIABLE
  LET MTH = MONTH
  LET X = RANDOM.F(5)
  IF (X<0.07 AND MTH=4) OR (X<0.13 AND (MTH=1 OR MTH=3)) OR
                                      (X<0.24 AND MTH = 2)
     LET RAIN = 1
  ELSE
     LET RAIN = 0
  ALWAYS
  RETURN WITH RAIN
END ''^^^^^^^^^^^^^^^^^^^ ROUTINE WEATHER ^^^^^^^^^^^^^^^^^^^^
```

```
ROUTINE ROADRUN GIVEN IDEN YIELDING SUPPLY.TIME ''# NOTE 16

  DEFINE IDEN AS A RECURSIVE INTEGER VARIABLE
  DEFINE SUPPLY.TIME,FILL AND DISCHARGE AS REAL VARIABLES
  LET FILL = 50/24                              ''# NOTE 17
  LET DISCHARGE = 50/60
  LET SUPPLY.TIME = BA.DISTANCE(IDEN)/40
  IF SUPPLY.TIME > 18.0                       ''# NOTE 18
     LET SUPPLY.TIME = SUPPLY.TIME*4/3
  ALWAYS
  LET SUPPLY.TIME = SUPPLY.TIME + FILL + DISCHARGE
  RETURN WITH SUPPLY.TIME
END ''^^^^^^^^^^^^^^^^^^^ ROUTINE ROADRUN ^^^^^^^^^^^^^^^^^^^^
```

```
PROCESS FUEL.CHECK GIVEN FARM                    ''# NOTE 19
  DEFINE DEFICIENCY AND WORK.LEVEL AS REAL VARIABLES
  DEFINE FARM AS AN INTEGER VARIABLE
  DEFINE LOADS AS A RECURSIVE INTEGER VARIABLE
  DEFINE TRANSTIME AS A REAL VARIABLE
  DEFINE CONSUME.RATE AND FACTOR AS REAL VARIABLES
  CALL ROADRUN GIVING FARM YIELDING TRANSTIME
  LET FACTOR = TRANSTIME*0.6        ''# NOTE 20
  LET WORK.LEVEL = 0.8*BA.TANK(FARM)
  LET CONSUME.RATE = BA.HOURLY.USE(FARM)

  LET DEFICIENCY = WORK.LEVEL - BA.FUEL(FARM) -
           ((BA.PIPELINE(FARM) + BA.SUP.DELAY(FARM)) * 50) +
           (CONSUME.RATE*FACTOR) - BA.TRUCK.DELAY(FARM)*50
  IF DEFICIENCY > = 50.0 AND (END.OF.SIM - TIME.V) GT 0.000
     LET LOADS = TRUNC.F(DEFICIENCY/50)       ''# NOTE 21
    FOR I = 1 TO LOADS
        DO
           ACTIVATE A RESUPPLY GIVING FARM NOW
        LOOP
     RETURN
  ALWAYS
  RETURN
END ''^^^^^^^^^^^^^^^^^^^ PROCESS FUEL.CHECK ^^^^^^^^^^^^^^^^^^^^
```

```
ROUTINE DEMAND GIVEN USER YIELDING USAGE       ''# NOTE 22
  DEFINE USER AS A RECURSIVE INTEGER VARIABLE
  DEFINE USAGE, Y AND Z AS RECURSIVE REAL VARIABLES
  LET Z = BA.DEMAND(USER)
  LET Y = RANDOM.F(6)
  IF (HOUR.F(TIME.V) > 6 AND HOUR.F(TIME.V) < 21) OR (Y < 0.05)
     LET USAGE = ABS.F(NORMAL.F(Z,25.0,9))/14    ''# NOTE 23
  OTHERWISE
     LET USAGE = 0
  ALWAYS
  LET BA.HOURLY.USE(USER) = USAGE
  RETURN WITH USAGE
END ''^^^^^^^^^^^^^^^^^^^ ROUTINE DEMAND ^^^^^^^^^^^^^^^^^^^^^^
```

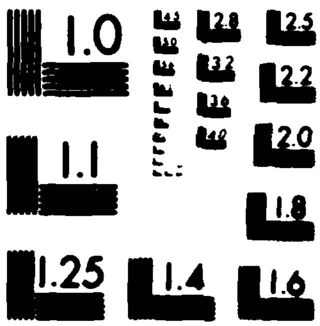
```
PROCESS STOCK.CHECK GIVEN DEPOT     ''CHECKS PORT FUEL # NOTE 24
  DEFINE DEPOT AS AN INTEGER VARIABLE
  IF PT.STOCK(DEPOT) < PT.REORDER.PT(DEPOT) AND FLAG NE FLYING
     ACTIVATE A SHIPMENT NOW
  ALWAYS
  IF (END.OF.SIM - TIME.V) GT 1.000
     REACTIVATE A STOCK.CHECK GIVING DEPOT IN 1 DAY
  ALWAYS
  RETURN
END ''^^^^^^^^^^^^^^^^^^^ PROCESS STOCK.CHECK ^^^^^^^^^^^^^^^^^
```

```
PROCESS SUCK GIVEN OPS            ''CONSUMES BASE FUEL # NOTE 25
  DEFINE OPS AND GO.NO.GO AS INTEGER VARIABLES
  DEFINE USE.RATE AS A RECURSIVE REAL VARIABLE
  CALL OP.STATUS GIVING OPS YIELDING GO.NO.GO
  IF GO.NO.GO = NO.GO
    JUMP AHEAD
  OTHERWISE
     CALL DEMAND GIVING OPS YIELDING USE.RATE
     SUBTRACT USE.RATE FROM BA.FUEL(OPS)
  HERE
  IF (END.OF.SIM - TIME.V)*24 GT 1.000
     ACTIVATE A FUEL.CHECK GIVING OPS IN 1 HOUR
     REACTIVATE A SUCK GIVING OPS IN 1 HOUR
  ALWAYS
  RETURN
END ''^^^^^^^^^^^^^^^^^^^  PROCESS SUCK  ^^^^^^^^^^^^^^^^^^^^^^
```

AD-A147 180 DISTRIBUTION AND STORAGE OF AVIATION TURBINE FUEL FOR MILITARY OPERATIONS..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. D A WHITTY 2/2

UNCLASSIFIED SEP 84 AFIT/GLM/LSM-84S-63 F/G 21/4 NL

END


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

```
ROUTINE OP.STATUS GIVEN QUERY YIELDING MESSAGE      ''# NOTE 26
  DEFINE QUERY AND MESSAGE AS RECURSIVE INTEGER VARIABLES
  DEFINE MARGIN AS A RECURSIVE REAL VARIABLE
  LET MARGIN = BA.FUEL(QUERY) - BA.RESERVE(QUERY)
  IF MARGIN NO GREATER THAN 0 AND BA.AVAIL.FUEL(QUERY) NE 0
     LET BA.AVAIL.FUEL(QUERY) = 0
     LET BA.STOP.TM(QUERY) = TIME.V
     LET MESSAGE = NO.GO
     RETURN WITH MESSAGE
  ALWAYS
  IF MARGIN GT 0 AND BA.AVAIL.FUEL(QUERY) EQ 0
     LET BA.AVAIL.FUEL(QUERY) = MARGIN
     LET BA.BEGIN.TM(QUERY) = TIME.V
     ADD (BA.BEGIN.TM(QUERY) - BA.STOP.TM(QUERY)) TO
                               BA.IDLE.TIME(QUERY)
     LET MESSAGE = GO.GO
  ALWAYS
  IF MARGIN GT 0 AND BA.AVAIL.FUEL (QUERY) NE 0
     LET MESSAGE = GO.GO
  ALWAYS
  RETURN WITH MESSAGE
END ''^^^^^^^^^^^^^^^^^^^ PROCESS OP.STATUS ^^^^^^^^^^^^^^^^^^^
```

```
EVENT CLEAR.PORTS                                    ''# NOTE 27
  DEFINE I AND J AS RECURSIVE INTEGER VARIABLES
  IF QUEUE IS NOT EMPTY
     FOR J = 1 TO N.BASE
     DO
       IF BA.SUP.DELAY(J) NE 0 AND QUEUE IS NOT EMPTY
          FOR I = 1 TO BA.SUP.DELAY(J)
          DO
            REMOVE THE FIRST RESUPPLY FROM QUEUE
            DESTROY RESUPPLY
          LOOP
       ALWAYS
     LOOP
  ALWAYS
  RETURN
END ''^^^^^^^^^^^^^^^^^^^^^^ EVENT CLEAR.PORTS ^^^^^^^^^^^^^^^^
```

```
ROUTINE STOP.SIM                                          ''# NOTE 28
  FOR EACH BASE
    DO
      IF BA.STOP.TM(BASE) GT BA.BEGIN.TM(BASE)
         ADD (TIME.V - BA.STOP.TM(BASE)) TO BA.IDLE.TIME(BASE)
      ALWAYS
    LOOP
  FOR EACH BASE
     ADD HOURS.V*BA.IDLE.TIME(BASE) TO IDOL.TM       ''# NOTE 29
  ADD IDOL.TM TO TOT.IDOL
  FOR EACH PORT
    DO                                             ''# NOTE 30
      LET MU.STOCK(PORT) = AV.STOCK(PORT)
      LET MU.Q.TRUCK(PORT) = AV.QUEUE(PORT)
      LET MU.U.TRUCK(PORT) = (AV.USED(PORT)/U.TRUCK(PORT))*100
    LOOP
  FOR EACH BASE
    DO
      LET MU.FUEL(BASE) = AV.FUEL(BASE)
      LET MU.IDLE(BASE) = BA.IDLE.TIME(BASE)
    LOOP
  RESET TOTALS OF BA.ORDER,BA.FUEL,PT.STOCK,     ''# NOTE 31
              N.Q.TRUCK AND N.X.TRUCK
  FOR EACH BASE
  DO
     LET BA.STOP.TM(BASE) = 0.0
     LET BA.BEGIN.TM(BASE) = 0.0
     LET FLYING = 0
     LET STCK.POSITION = 0
     LET BA.IDLE.TIME(BASE) = 0.0
     LET BA.SUP.DELAY(BASE) = 0
     LET BA.TRUCK.DELAY(BASE) = 0
  LOOP
  LET FIRST.STOCK = 0
  FOR EACH PORT
     LET PT.DRAIN(PORT) = 0.0
  ''CALL PRINTOUT(2)
  ''FOR EACH BASE
     ''CALL STATS(BASE)
  RETURN
END''^^^^^^^^^^^^^^^^^^ ROUTINE STOP.SIM ^^^^^^^^^^^^^^^^^^^^^^
```

```
ROUTINE ASSINFO  ''ASSIGNS STARTING VALUES          # NOTE 32

  LET N.PORT = 2
  CREATE EVERY PORT

  LET PT.NAME(DARWIN)="PORT.DARWIN"
  LET PT.CAPACITY(DARWIN)=19937
  LET PT.STOCK(DARWIN) = ABS.F(NORMAL.F(9624.0,5836.0,5)) ''# NOTE 33
  LET PT.REORDER.PT(DARWIN) = 7680                    ''# NOTE 38

  LET PT.NAME(HEDLAND)="PORT.HEDLAND"
  LET PT.CAPACITY(HEDLAND)=4551
  LET PT.STOCK(HEDLAND) = ABS.F(NORMAL.F(2823.0,1188.0,4))''# NOTE 33
  LET PT.REORDER.PT(HEDLAND) = 1050       ''# NOTE 38

  LET N.BASE=4
  CREATE EVERY BASE

  LET BA.NAME(DWN)="DARWIN"
  LET BA.NAME(TDL)="TINDAL"
  LET BA.NAME(DBY)="DERBY"
  LET BA.NAME(LMO)="LEARMONTH"

  LET BA.TANK(DWN)=2220
  LET BA.TANK(TDL)=1654
  LET BA.TANK(DBY)=2646
  LET BA.TANK(LMO)=1737

  LET BA.DEMAND(DWN)=230                              ''# NOTE 34
  LET BA.DEMAND(TDL)=700
  LET BA.DEMAND(DBY)=350
  LET BA.DEMAND(LMO)=350


  LET BA.RESERVE(DWN)=300                             ''# NOTE 35
  LET BA.RESERVE(TDL)=420
  LET BA.RESERVE(DBY)=400
  LET BA.RESERVE(LMO)=430

  LET BA.DISTANCE(DWN) = 20
  LET BA.DISTANCE(TDL) = 354
  LET BA.DISTANCE(DBY) = 1717
  LET BA.DISTANCE(LMO) = 850

  LET BA.PORT(DWN) = "PORT.DARWIN"
  LET BA.PORT(TDL) = "PORT.DARWIN"
  LET BA.PORT(DBY) = "PORT.DARWIN"
  LET BA.PORT(LMO) = "PORT.HEDLAND"
```

```
    LET BA.FUEL(DWN) = ABS.F(NORMAL.F(1743.0,35.0,5))''# NOTE 33
    LET BA.FUEL(TDL) = ABS.F(NORMAL.F(1265.0,111.0,4))
    LET BA.FUEL(DBY) = ABS.F(NORMAL.F(2043.0,93.0,3))
    LET BA.FUEL(LMO) = ABS.F(NORMAL.F(1240.0,84.0,2))

    LET BA.AVAIL.FUEL(DWN) = BA.FUEL(DWN) - BA.RESERVE(DWN)
    LET BA.AVAIL.FUEL(TDL) = BA.FUEL(TDL) - BA.RESERVE(TDL)
    LET BA.AVAIL.FUEL(DBY) = BA.FUEL(DBY) - BA.RESERVE(DBY)
    LET BA.AVAIL.FUEL(LMO) = BA.FUEL(LMO) - BA.RESERVE(LMO)

    LET BA.ORDER(DWN) = 0                              ''# NOTE 36
    LET BA.ORDER(TDL) = INT.F(0.2*U.TRUCK(DARWIN))
    LET BA.ORDER(DBY) = INT.F(0.6*U.TRUCK(DARWIN))
    LET BA.ORDER(LMO) = INT.F(0.8*U.TRUCK(HEDLAND))

    LET BA.PIPELINE(DWN) = 0                           ''# NOTE 37
    LET BA.PIPELINE(TDL) = INT.F(0.75*BA.ORDER(TDL))
    LET BA.PIPELINE(DBY) = INT.F(0.75*BA.ORDER(DBY))
    LET BA.PIPELINE(LMO) = INT.F(0.75*BA.ORDER(LMO))

    FOR EACH PORT
       DO
         FOR EACH BASE WITH BA.PORT(BASE) = PT.NAME(PORT)
            DO
              ADD BA.DEMAND(BASE) TO PT.DRAIN(PORT) ''# NOTE 38
            LOOP
       LOOP


    CREATE EVERY SHIP(1)
    LET U.SHIP(1)=1

    RETURN
  END ''^^^^^^^^^^^^^^^^^^ ROUTINE ASSINFO ^^^^^^^^^^^^^^^^^^^^^
```

```
ROUTINE SUM.STATS                                   ''# NOTE 39
  SKIP 5 LINES
  PRINT 2 LINES WITH FLEET.OF.TRUCKS THUS
  STATISTICAL SUMMARY FOR ** TRUCKS
  #######################################################
  SKIP 2 LINES
  PRINT 2 LINES THUS
      PORT      MEAN STOCK  SD STOCK  TRUCK USE  TRUCK QUEUE
  ============ ========== ======== ========= ===========
  SKIP 1 LINES
  FOR EACH PORT
  DO
    PRINT 1 LINE WITH PT.NAME(PORT),MOM.STCK,SSD.STCK,
             MOM.USED,MOM.Q THUS
  ************   ******.*    *****.*    **.** %     ****.**
  LOOP
  SKIP 3 LINES
  PRINT 2 LINES THUS
    BASE      MEAN FUEL  SD FUEL  MEAN IDLE TIME  SD IDLE
  ========== ========= ======= ============== =======
  SKIP 1 LINES
  FOR EACH BASE
  DO
    PRINT 1 LINE WITH BA.NAME(BASE),MOM.FUEL,SSD.FUEL,
              MN.IDLE,VAR.IDLE THUS
  **********  *****.**   ****.**      *****.**      ****.**
  LOOP
  SKIP 5 LINES
  LET AV.IDOL = 0
  LET TOT.IDOL = 0
  RETURN
END ''^^^^^^^^^^^^^^^^ ROUTINE SUM.STATS ^^^^^^^^^^^^^^^^^^^^^^
```

```
ROUTINE STATS(AIRFIELD)        ''STATISTICAL OUTPUT # NOTE 40
  DEFINE AIRFIELD, M AS INTEGER VARIABLES
  DEFINE SYMBOL AS AN ALPHA VARIABLE
  LET SYMBOL = "#"
  PRINT 8 LINES WITH BA.NAME(AIRFIELD),
                     AV.PIPE(AIRFIELD),
                     SD.PIPE(AIRFIELD),
                     MAX.PIPE(AIRFIELD),
                     MIN.PIPE(AIRFIELD),
                     BA.ORDER(AIRFIELD),
                     BA.PIPELINE(AIRFIELD),
                     TOT.IDLE(AIRFIELD) THUS
 FOR ************      MEAN NO. OF TRUCKS    = ***.***
                          STD.DEV            = ***.***
                          MAXIMUM NUMBER     = ***.***
                          MINIMUM NUMBER     = ***.***
                          NO.IN TRANSIT      = ***.***
                          NO. STILL ENROUTE  = ***.***
                       TOTAL IDLE TIME       = ***.***

  PRINT 5 LINES WITH BA.NAME(AIRFIELD),
                     AV.FUEL(AIRFIELD),
                     SD.FUEL(AIRFIELD),
                     MAX.FUEL(AIRFIELD),
                     MIN.FUEL(AIRFIELD) THUS
 FOR ************      MEAN FUEL LEVEL     = *****.***
                       STD.DEV             = *****.***
                       MAXIMUM LEVEL       = *****.***
                       MINIMUM LEVEL       = *****.***

  RETURN
END ''^^^^^^^^^^^^^^^^^^ ROUTINE STATS ^^^^^^^^^^^^^^^^^^^^^^
```

```
ROUTINE PRINTOUT(SITU)    ''START & FINISH CONDITIONS # NOTE 40
  DEFINE SITU AS AN INTEGER VARIABLE
  IF SITU = 1 PRINT 3 LINES THUS

        THE MODEL'S STARTING CONDITIONS WERE:

  ELSE PRINT 3 LINES THUS

        THE MODEL'S CONCLUDING CONDITIONS WERE:

  ALWAYS
  FOR EACH PORT
     PRINT 12 LINES WITH PT.NAME(PORT),
                         PT.CAPACITY(PORT),
                         PT.STOCK(PORT),
                         PT.REORDER.PT(PORT),
                         AV.STOCK(PORT),
                         SD.STOCK(PORT),
                         AV.QUEUE(PORT),
                         SD.QUEUE(PORT),
                         MAX.QUEUE(PORT) THUS
  ***************

        BULK FUEL STORAGE CAPACITY        = ***** TONNES
        CURRENT FUEL INVENTORY            = ***** TONNES
        REORDER POINT                     = ***** TONNES
        MEAN STOCK LEVEL                  = ******.** TONNES
        STOCK LEVEL STD DEV               =  *****.**
        MEAN QUEUE FOR TRUCKS             = ***.***
        STD.DEV                           = ***.***
        MAXIMUM QUEUE                     = ***.***

  FOR EACH BASE
     PRINT 10 LINES WITH BA.NAME(BASE),
                          BA.TANK(BASE),
                          BA.DEMAND(BASE),
                          BA.FUEL(BASE),
                          BA.RESERVE(BASE),
                          BA.PORT(BASE),
                          BA.DISTANCE(BASE) THUS
  ****************

        BASE FUEL STORAGE CAPACITY       = ***** TONNES
        AVERAGE DAILY DEMAND OF AVTUR    = ***** TONNES
        CURRENT OPERATIONAL FUEL STOCK   = ***** TONNES
        DESIRED OPERATIONAL RESERVE      = ***** TONNES
        PORT SERVING BASE:                 ***************
               AT A DISTANCE OF            **** KILOMETRES

  RETURN
END ''^^^^^^^^^^^^^^^^^^ ROUTINE PRINTOUT ^^^^^^^^^^^^^^^^^^^^^
```

Appendix C: Program Documentation

The following notes follow the order of the processes, routines and events as they appear in the simulation program at Appendix B.

Notes on MAIN

1. The SAVESEED procedure ensures that the starting number for a random seed is saved at the beginning of each run of 30 cycles and replaced for the next run so that the starting values for random functions are replicated exactly for successive truck fleet sizes.

2. The proportion of units of truck resources assigned to each port was calculated from early pilot runs which yielded the values required to reduce system idle time to zero. The results of those runs confirmed that the proportion *yielded approximates* closely the results of a manual calculation as follows.

a. For each base, its distance from port is multiplied by its daily fuel. The sum of all these products for all bases is denoted y.

b. For a given port, the base products calculated in (a) above are summed over all bases served by the port. The sum of those customer products is then denoted x.

c. The proportion of total truck resources assigned to a port is the ratio x/y unless that ratio will yield a value of less than two.

d. If the value of the ratio for a particular port is less than two, two trucks are assigned to that port and the total of truck

resources reduced by two in the calculations for other ports. Two trucks are assessed as the minimum necessary port resource to provide a high probability that one at least will always be available. (The manual calculation was used to assign truck resources to ports in several of the simulation runs which used different port/base combinations and/or demand levels.)

3. A cycle time of 12 days was chosen because this is the time required for one complete bulk resupply by ship, i.e., the time for the ship to leave the Perth refinery, restock all bulk storages, and return to Perth.

Notes on Routine BEGIN.DATE

4. The routine returns a starting date in the year 1984 by month (MM) and day (DD). The RANDI.F function returns and integer value lying between the minimum and maximum values specified as the first two numbers in the following brackets. The third number is the random seed. The MM value for the month, chosen randomly as an integer between 1 and 12, gives complete coverage over the year. The maximum value specified for the starting day (DD) is 28 which limits coverage slightly, but extending the routine to permit return of a number from 29 to 31 in specified circumstances was not considered necessary.

Notes on Routine DUES.IN

5. Because randomization of the starting value for port stock could yield a value lower than the port's reorder point (the point at which the system would have called for a fuel shipment), this routine

calculates whether and when a shipment should have been due given the actual starting values of port stocks. The time for first stock is retained as a global variable and is used after the first stock check reveals that a port's stock is lower than its reorder point.

Notes on Process INITIAL.PIPE

6. Process INITIAL.PIPE inserts full fuel trucks onto the roads serving operational bases to approximate the steady-state condition of an operating fuel distribution system. The values for the pipelines are calculated in Routine ASSINFO (see Notes 36 and 37 below). The appropriate number of trucks is then staggered at equidistant intervals on the road from supply port to operational base, an arrival time is calculated for each truck, an arrival scheduled, and the empty truck is placed in the returning pipeline.

Notes on Process GIVE.BACK

7. Process GIVE.BACK places empty trucks in the return pipeline from operating bases to supply port. The procedure for assignment is similar to that used in INITIAL.PIPE (see also Notes 6 and 12).

Notes on Process ARRIVAL

8. Process ARRIVAL ensures that base tanks are not overfilled. If there is no room in the tank for the arriving truckload, the truck waits for 30 minutes before trying again to unload. When successful, the fuel level in the base tank is adjusted. The process is activated either from Process INITIAL.PIPE or Process RESUPPLY.

Notes on Process SHIPMENT

9. Process SHIPMENT simulates the restocking of ports by ship from Perth refinery. It is actiated by Process STOCK.CHECK when any port's stock level falls below its reorder point (see Note 38 below). The fir restock of the first port is scheduled according to the value of FIRST.STOCK returned by Routine DUES.IN. Thereafter the restock times reflect the sailing time between the various ports. No attempt is made to simulate ship loading or unloading in the model.

Notes on Process RESTOCK

10. Process RESTOCK simply fills port storage capacities on arrival of the resupply ship, and releases any queued resupplies which have been kept waiting.

Notes on Process RESUPPLY

11. Process RESUPPLY is called by Process FUEL.CHECK when base fuel stocks fall below the working level (see Note 19 below). It incorporates firstly a check on whether the resupply port has stock to accommodate the request. If not, the resupply is filed in a resupply queue. If so, the process requests a truck resource. When a truck becomes available, a truckload of fuel is deducted from port stocks, a call is made to Routine WEATHER to determine whether there will be any rain delay (see Note 15 below). If so, the process calculates a random rain delay (see Note 13).

12. DAZE.BACK is a variable representing the transit time for empty trucks from base to home port. The program uses a simple

calculation of DISTANCE/SPEED with SPEED expressed as kilometres per day (i.e., 60 kilometres per hour = 1440 km per day).

13. Rain delay is simulated as a random figure returned from a LOGNORMAL distribution with a mean of one day and a standard deviation of .5 days. No empirical data was available on what actual delays might be experienced, but the LOGNORMAL distribution was chosen on the basis that all returned values would be positive, and a sample return from the long tail of the distribution could realistically approximate a serious mishap or delay when an accident might occur, a bridge be knocked down, or significant proportion of road washed out.

14. Normal transit time from port to base is returned via a call to Routine ROADRUN (see Notes 16-18 below). This value is then added to any rain delay, an arrival time calculated, and an ARRIVAL scheduled. On completion of the arrival process, the empty truck is returned to its home port, and relinquished for further work.

Notes on Routine WEATHER

15. Routine WEATHER returns a probability of rain or no rain for a given month of the year. No empirical statistics as to sampling distribution were available, and the probabilities were calculated from the following figures showing average annual rainfall at Port Hedland.

Characteristics	Rainfall												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average Points	193	365	176	74	130	58	46	17	4	6	9	86	1,164
Highest Points	1,969	1,432	1,716	1,386	873	696	384	584	99	129	336	1,023	4,013
Lowest Points	0	0	0	0	0	0	0	0	0	0	0	0	125
Highest One Day Points	1,524	955	1,113	469	638	560	185	364	85	127	306	900	1,113
Wet Days Average Number	4	6	4	2	3	2	2	1	1	1	0	1	27

Taking the dangerously rainy season as January to April each year, the statistics were incorporated in the model as probabilities calculated as the average number of wet days in a month/number of days in the month, yielding a 13% probability of heavy rain in January or March, a 24% probability in February, and a 7% probability in April.

Notes on Routine ROADRUN

16. Routine ROADRUN calculates a total work time for trucks to respond to resupply calls.

17. Variables FILL and DISCHARGE take on values for the time taken to fill and empty a 50 tonne tanker respectively. Advice from the Australian Department of Defence (DoD) was that the flow rate for filling tankers was 24 tonnes per hour, and the flow rate for discharge was 60 tonnes per hour.

18. Road time is calculated at a travel rate for fuel tankers of 40km/hr. If travel time exceeds 18 hours, the simple calculation of base distance/speed is multiplied by a factor of 4/3 since the operational rule advised by Australian DoD was that truck crews would only be required to operate for 18 hours in 24.

Notes on Process FUEL.CHECK

19. This process checks the fuel at an operational base, relates it to the working fuel level (advice from Royal Australian Air Force is

that the working fuel level is normally around 80% of tank capacity), calculates any deficiency, and orders resupplies accordingly.

20. The key to the process is the deficiency calculation. In words, the program calculates the relevant base's working fuel level as 80% of tank capacity and subtracts from that the amount of fuel in the tank to provide an initial figure for DEFICIENCY. DUES.IN are then subtracted from the initial deficiency, i.e., those truckloads already ordered and either in transit to the base, queued awaiting truck resources, or queued awaiting port stocks. The resultant figure is then increased by the amount of fuel the base will consume while the ordered trucks are in transit, i.e., the ruling consumption rate multiplied by a FACTOR of 0.6 which represents the proportion of normal operating hours in any given day.

21. If the deficiency calculation returns a positive value greater then 50, the number of truckloads is calculated and resupplies ordered accordingly.

Notes on Routine DEMAND

22. Routine DEMAND returns hourly fuel usage rate in response to a call from Process SUCK, which simulates base consumption.

23. During "normal" operating hours - arbitrarily set at 0700-2000 - the hourly usage rate is obtained randomly from a normal distribution with mean equal to the average total daily demand and an arbitrarily chosen standard deviation. No empirical evidence is yet available to assess the adequacy of the chosen distribution.

To simulate the occurrence of out of hours operations, a random number generator returns a number between .01 and .99. If the number is less than .05 (a 5% probability) out of hours operations are assumed to be occurring and an hourly usage rate is calculated.

Notes on Process STOCK.CHECK

24. This process simply checks port stock levels, and, if the level is lower than the port's reorder point, activates Process SHIPMENT - the resupply ship from Perth refinery. The calculation for the port's reorder point is shown at Note 38 below.

Notes on Process SUCK

25. Process SUCK, activated hourly, simulates base consumption of AVTUR. A call to Routine OP.STATUS establishes whether the base fuel level is above its emergency reserve. If so, a call to Routine DEMAND returns a random fuel usage rate, and the hour's usage is subtracted from the base fuel assets. If not, operations at the base are suspended.

Notes on Routine OP.STATUS

26. Routine OP.STATUS checks the margin of base fuel over its emergency reserve. If the margin is positive it returns a GO message to Process SUCK, and consumption takes place. If the margin is negative, a NO.GO message is returned, the time the base stops operations noted, and idle time starts to accumulate.

Notes on Event CLEAR.PORTS

27. Event CLEAR.PORTS is scheduled by MAIN to occur at the nominated end of the simulation. It is a "housekeeping" event. In preparation for the next cycle, it empties any resupply queue which might have accumulated at a port awaiting stock.

Notes on Routine STOP.SIM

28. Routine STOP.SIM is called by MAIN after the programmed end of the simulation period. It picks up any "hanging" periods of base idle time (i.e., if operations have been suspended but not restarted, the idle time calculation is made from the stop time to the end of simulation).

29. Idle time for individual bases is summed to provide a total figure (in hours) for the system's operations over the twelve day cycle.

30. This routine also transfers accumulated averages for port and base fuel levels, port truck queues and usage, and base idle time into global variable which then become the object of statistical tallying to provide a mean of means calculation at the end of the 30th cycle for a given truck size.

31. Finally, the routine resets global variables in preparation for the next 12 day run.

Notes on Routine ASSINFO

32. In general, this routine provides starting values for global variables for any twelve day cycle. Some variables, e.g., names of ports and bases and tank capacities, are unchanged from one twelve day cycle to the next, but whenever possible the values are randomized as explained below.

33. The starting value for port stock levels and base fuel levels are given by a random sampling from a normal distribution with mean and variance as indicated by earlier simulation runs. Although a mean of means calculation was available which would ensure that the distribution was normal, population statistics were preferred because of the wider variance and hence larger range for random sampling. There is no empirical evidence yet available to demonstrate whether the assumption of a normal distribution for population statistics is correct.

34. The demand figures used for the hypothetical situation posited for the simulation represent only a best estimate of combined civil and military demand. No empirical evidence is availble but the estimate has been confirmed as "useful" by the Australian DoD.

35. The reserve figure was arbitrarily set at 25% of tank capacity in the case of Tindal and Learmonth and 15% of tank capacity for Darwin and Derby. This provides for 60% of a full day's operations for Tindal, which is relatively close to its supplying port, approximately 120% of a full day's operations for Learmonth and Derby, which are relatively distant, and 130% for Darwin which is very close to its supplying port, but could have to backstop Tindal operations.

36. The BA.ORDER variable is the total of trucks in the resupply pipeline both bound for and returning from a base. Darwin base, only 20km from its supply port, is assumed to have no pipeline. Early runs indicated that for the other bases, some 80% of truck resources would be in the pipeline when the system was operating at steady-state. The split of that 80% of Port Darwin's trucks as between Tindal (20%) and Derby (60%) is as indicated by those earlier runs.

37. Of trucks in the resupply pipeline, the proportion between those inbound for a base (BA.PIPELINE) and the total of inbound and returning (BA.ORDER) was found to be 75%, reflecting the slower tavelling speed for fully laden trucks, and the passing of time to fill and time to empty before a truck is released by the inbound pipeline.

38. The global variable PT.DRAIN port totals the daily demand on any port from all of its operating bases. When this figure is multiplied by the number of days it would take a shipment to reach the port, it provides that port's reorder point.

Notes on Routine SUM.STATS

39. Routine SUM.STATS provides a succinct statistical summary at the end of each 30 cycles for a given truck fleet size.

Notes on Routine STATS and Routine PRINTOUT

40. These routines provide summaries of port and base statistics and were used in earlier runs of the model to collect the statistics later used to approximate steady-state conditions. They are now "disconnected" but are displayed for completeness.

Appendix D: Letter From Major General A. D. Powell, Australian Department of Defence

FROM: MAJOR GENERAL A. D. POWELL

DEPARTMENT OF DEFENCE
CAMPBELL PARK OFFICES
CANBERRA, A.C.T. 2600

1 June 1984

Mr D.A. Whitty
2754 Stauffer Drive
BEAVERCREEK OHIO 45385 USA

My dear Dennis

I thank you for the opportunity which you gave me to review the thesis which you have developed. I found your concepts and treatment of issues are most interesting. I see the techniques and the presentation which you use in the model will be of considerable use in the clarification of a wide range of considerations related to the provision of fuel.

The approach which you have taken should enable us to adequately take account of the difficulties we face, due to the size of our continent, the locations of our industrial base and the potential areas in which our forces will be involved. We could therefore readily translate the concept and the methodology which you have developed to our present and future studies on the provision of fuel.

I appreciate the effort which you have put into developing your position and would wish you to know that it will greatly assist us in our studies of various supply activities.

Yours
A D Powell

Appendix E: Statistical Analysis of Output for Selected Experiments

Action: Doubling Port Hedland Bulk Storage Capacity
[Line No. 1, Figure 15]

a. Estimates of Idle Time for 12 day Cycle, 20 Trucks

226.93	186.00	208.90	203.97	253.97
227.97	206.00	180.90	225.00	196.97
184.97	219.00	165.97	227.93	152.97
206.93	180.97	214.97	199.93	179.97
187.93	207.00	198.97	177.97	230.00
211.93	171.97	189.97	208.93	196.00

Mean: 193.96 SD: 40.75 90%CI: 181.90 —> 206.03

b. Estimates of Idle Time for 12 Day Cycle, 25 Trucks

93.97	91.97	124.93	116.93	131.93
133.97	118.97	114.93	122.97	103.00
101.93	133.00	87.93	99.97	79.00
98.90	86.93	95.00	101.00	119.97
109.97	93.00	99.97	93.00	104.00
106.93	125.00	100.97	82.00	91.97

Mean: 99.16 SD: 29.69 90%CI: 90.29 —> 107.95

c. **Estimates of Idle Time for 12 Day Cycle, 30 Trucks**

56.00	36.00	60.93	75.00	100.00
49.00	65.97	44.00	50.00	50.00
51.00	62.17	62.97	32.97	36.00
49.00	46.00	42.30	38.00	48.00
45.97	40.00	38.97	31.97	44.97
40.00	47.97	36.00	39.97	36.00

Mean: 46.70 **SD:** 16.05 **CI:** 41.95 —> 51.45

d. **Estimates of Idle Time for 12 Day Cycle, 35 Trucks**

00.00	00.00	00.00	00.00	00.00
00.00	4.00	00.00	00.00	00.00
1.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00

Mean: 00.16 **SD:** 00.92 **CI:** 00.00 —> 00.37

e. Estimates of Idle Time for 12 Day Cycle, 40 Trucks

00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	42.00	00.00	00.00
31.00	00.00	00.00	00.00	00.00

Mean: 2.35 SD: 9.00 CI: 00.00 —> 5.01

f. Estimates of Idle Time for 12 Day Cycle, 45 Trucks

00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00

Mean: 00.00 SD: 00.00 CI: 00.00

Action: **Building 4550 Tonne Bulk Storage Capacity at Exmouth [Line No. 2, Figure 15]**

a. **Estimates of Idle Time for 12 Day Cycle, 20 Trucks**

38.97	34.97	29.00	33.00	74.00
97.93	52.00	34.00	37.00	45.00
31.00	39.97	32.00	42.00	29.00
22.00	26.00	54.00	30.00	40.00
40.00	32.00	40.00	27.00	35.00
36.00	31.00	34.00	27.00	37.00

Mean: 37.44 SD: 16.04 CI: 32.69 —> 42.19

b. **Estimates of Idle Time for 12 Day Cycle, 25 Trucks**

00.00	00.00	00.00	00.00	40.00
68.00	31.97	00.00	6.00	00.00
00.00	4.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	10.00	00.00	00.00	00.00

Mean: 5.16 SD: 14.56 CI: 0.85 —> 9.47

c. **Estimates of Idle Time for 12 Day Cycle, 30 Trucks**

00.00	00.00	00.00	20.00	44.97
32.00	56.97	24.00	00.00	1.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	67.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00

Mean: 8.19 SD: 17.72 CI: 2.94 —> 13.44

d. **Estimates of Idle Time for 12 Day Cycle, 35 Trucks**

00.00	00.00	00.00	26.00	15.00
38.00	35.97	5.97	00.00	00.00
00.00	10.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	68.00
00.00	00.00	00.00	00.00	00.00

Mean: 6.41 SD: 15.15 CI: 1.92 —> 10.90

e. **Estimates of Idle Time for 12 Day Cycle, 40 Trucks**

00.00	00.00	00.00	26.00	15.00
00.00	4.00	00.00	11.00	34.00
00.00	00.00	00.00	00.00	00.00
49.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	54.00	00.00	00.00	00.00

Mean: 6.23 SD: 14.27 CI: 2.00 —> 10.46

f. **Estimates of Idle Time for 12 Day Cycle, 45 Trucks**

00.00	00.00	00.00	00.00	22.00
51.00	10.00	00.00	8.00	00.00
00.00	21.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	44.00
00.00	00.00	00.00	00.00	00.00
52.00	00.00	00.00	00.00	00.00

Mean: 6.71 SD: 14.96 CI: 2.28 —> 11.14

Action: Building 4550 Tonne Bulk Storage Capacity at Derby [Line No. 3, Figure 15]

a. Estimates of Idle Time for 12 Day Cycle, 20 Trucks

92.97	81.97	109.97	99.00	106.00
102.97	94.97	110.00	98.93	107.93
100.93	84.97	91.93	92.97	75.97
89.97	83.97	68.97	78.97	90.97
77.97	71.97	68.93	70.97	70.97
75.97	83.97	61.97	83.93	71.86

Mean: 83.93 SD: 20.28 90%CI: 72.84 —> 90.02

b. Estimates of Idle Time for 12 Day Cycle, 25 Trucks

8.00	15.00	35.00	28.00	34.00
31.00	28.00	12.00	98.00	16.00
22.97	27.00	7.00	35.00	13.00
21.00	19.00	15.00	15.00	8.00
6.00	7.00	11.00	32.00	10.00
9.00	23.00	7.00	17.00	10.00

Mean: 19.99 SD: 17.22 90%CI: 14.82 —> 25.16

c. Estimates of Idle Time for 12 Day Cycle, 30 Trucks

00.00	00.00	00.00	00.00	00.00
9.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00

Mean: 0.29 SD: 1.50 90%CI: 0.00 —> 0.73

d. Estimates of Idle Time for 12 Day Cycle, 35 Trucks

00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	26.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	67.00	00.00
00.00	71.00	00.00	17.00	00.00
00.00	00.00	00.00	00.00	2.00

Mean: 5.90 SD: 17.40 90%CI: 0.00 —> 11.02

e. Estimates of Idle Time for 12 Day Cycle, 40 Trucks

00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	26.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	67.00	00.00
00.00	70.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00

Mean: 5.25 SD: 17.23 90%CI: 0.15 —> 10.35

f. Estimates of Idle Time for 12 Day Cycle, 45 Trucks

00.00	00.00	00.00	00.00	3.00
00.00	00.00	00.00	00.00	00.00
00.00	20.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00
00.00	00.00	00.00	00.00	00.00

Mean: 0.65 SD: 3.53 90%CI: 0.00 —> 1.70

Appendix F: Statistical Information Provided on Ports and Operational Bases

EXAMPLES OF STATISTICAL OUTPUT - BULK STORAGE

STATISTICAL SUMMARY FOR 20 TRUCKS (HEDLAND DOUBLED)
###

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	14290.7	342.7	98.68 %	29.15
PORT.HEDLAND	7515.9	193.0	99.89 %	44.89

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1212.67	4.98	0.00	0.00
TINDAL	520.15	3.95	4.04	0.40
DERBY	1010.84	25.55	1.31	0.34
LEARMONTH	591.80	9.36	3.00	0.53

STATISTICAL SUMMARY FOR 25 TRUCKS (HEDLAND DOUBLED)
###

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	14044.6	321.8	99.07 %	23.00
PORT.HEDLAND	7377.7	165.6	99.90 %	39.24

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1394.48	2.70	0.00	0.00
TINDAL	580.15	6.44	2.21	0.26
DERBY	1146.06	27.38	0.24	0.25
LEARMONTH	636.05	9.85	1.95	0.40

STATISTICAL SUMMARY FOR 30 TRUCKS (HEDLAND DOUBLED)
###

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	13955.9	418.0	97.69 %	19.91
PORT.HEDLAND	7041.0	125.9	99.65 %	27.57

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1461.94	3.51	0.00	0.00
TINDAL	616.96	6.54	1.47	0.31
DERBY	1463.49	25.41	0.00	0.00
LEARMONTH	755.11	19.76	0.54	0.36

STATISTICAL SUMMARY FOR 35 TRUCKS (HEDLAND DOUBLED)
###

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	13199.8	233.9	98.14 %	9.10
PORT.HEDLAND	7045.3	72.1	99.67 %	16.01

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1634.13	4.38	0.00	0.00
TINDAL	926.19	15.70	0.00	0.01
DERBY	1723.31	32.63	0.00	0.00
LEARMONTH	969.82	35.64	0.01	0.03

STATISTICAL SUMMARY FOR 40 TRUCKS (HEDLAND DOUBLED)
###

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	13276.7	386.1	94.41 %	2.39
PORT.HEDLAND	6807.1	56.6	97.66 %	3.51

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1713.20	2.86	0.00	0.00
TINDAL	1159.57	10.72	0.10	0.38
DERBY	1974.82	26.10	0.00	0.00
LEARMONTH	1223.13	28.94	0.00	0.00

STATISTICAL SUMMARY FOR 45 TRUCKS (HEDLAND DOUBLED)
###

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	13185.3	353.9	81.85 %	0.47
PORT.HEDLAND	6767.6	40.9	89.50 %	0.35

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1731.97	1.86	0.00	0.00
TINDAL	1234.32	2.57	0.00	0.00
DERBY	2045.58	10.21	0.00	0.00
LEARMONTH	1298.63	13.59	0.00	0.00

STATISTICAL SUMMARY FOR 20 TRUCKS (EXMOUTH BULK STORE)
##

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	11771.7	330.1	98.96 %	19.62
PORT.HEDLAND	3484.4	68.4	99.01 %	17.73
PORT.EXMOUTH	3204.6	39.4	85.06 %	5.01

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1469.64	3.26	0.00	0.00
TINDAL	636.81	5.90	1.40	0.25
DERBY	1303.97	39.22	0.02	0.06
LEARMONTH	1078.15	112.18	0.19	0.55

STATISTICAL SUMMARY FOR 25 TRUCKS (EXMOUTH BULK STORE)
##

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	12664.9	544.9	98.45 %	7.51
PORT.HEDLAND	3146.0	100.1	98.79 %	6.47
PORT.EXMOUTH	3085.0	45.4	84.36 %	4.36

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1654.55	5.22	0.00	0.00
TINDAL	987.98	14.95	0.01	0.07
DERBY	1764.76	42.06	0.00	0.00
LEARMONTH	1111.12	100.08	0.21	0.62

STATISTICAL SUMMARY FOR 30 TRUCKS (EXMOUTH BULK STORE)

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	11340.4	331.1	81.07 %	0.48
PORT.HEDLAND	3157.5	90.1	93.73 %	0.98
PORT.EXMOUTH	3161.4	41.7	84.37 %	5.50

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1730.94	2.74	0.00	0.00
TINDAL	1232.19	7.59	0.13	0.53
DERBY	1995.45	21.42	0.00	0.00
LEARMONTH	1054.26	118.72	0.23	0.58

STATISTICAL SUMMARY FOR 35 TRUCKS (EXMOUTH BULK STORE)

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	12667.9	594.7	70.90 %	0.04
PORT.HEDLAND	3124.4	101.8	77.35 %	0.02
PORT.EXMOUTH	3157.9	56.6	82.73 %	4.87

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1738.28	2.18	0.00	0.00
TINDAL	1261.24	4.33	0.09	0.51
DERBY	2044.33	13.00	0.00	0.00
LEARMONTH	1087.76	112.20	0.18	0.43

STATISTICAL SUMMARY FOR 40 TRUCKS (EXMOUTH BULK STORE)
###

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	11530.7	359.7	59.50 %	0.06
PORT.HEDLAND	3190.1	70.0	69.95 %	0.00
PORT.EXMOUTH	3159.2	48.8	82.52 %	3.97

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1734.62	3.32	0.00	0.00
TINDAL	1250.31	8.59	0.18	0.57
DERBY	2040.25	15.34	0.00	0.00
LEARMONTH	1131.98	92.03	0.09	0.23

STATISTICAL SUMMARY FOR 45 TRUCKS (EXMOUTH BULK STORE)
###

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	11876.6	295.8	53.59 %	0.03
PORT.HEDLAND	3235.1	63.3	59.68 %	0.00
PORT.EXMOUTH	3166.1	52.8	82.47 %	3.87

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1736.18	3.32	0.00	0.00
TINDAL	1260.98	6.75	0.16	0.52
DERBY	2052.57	12.41	0.00	0.00
LEARMONTH	1137.20	93.36	0.13	0.41

STATISTICAL SUMMARY FOR 20 TRUCKS (DERBY WITH BULK)
##

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	12578.6	558.2	99.02 %	19.63
PORT.HEDLAND	3680.2	45.0	99.84 %	17.83
PORT.DERBY	3387.9	43.9	74.38 %	2.83

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1470.27	3.84	0.00	0.00
TINDAL	638.60	7.18	1.40	0.15
DERBY	1916.76	78.32	0.00	0.00
LEARMONTH	620.68	14.57	2.22	0.53

STATISTICAL SUMMARY FOR 25 TRUCKS (DERBY WITH BULK)
##

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	11791.0	322.3	92.95 %	2.73
PORT.HEDLAND	3461.6	39.8	99.38 %	14.62
PORT.DERBY	3326.4	31.2	76.76 %	2.99

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1702.65	7.41	0.00	0.00
TINDAL	1140.59	19.02	0.17	0.56
DERBY	1906.57	76.78	0.00	0.00
LEARMONTH	707.48	20.56	0.69	0.37

STATISTICAL SUMMARY FOR 30 TRUCKS (DERBY WITH BULK)
##

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	12441.2	631.2	81.50 %	0.33
PORT.HEDLAND	3227.6	35.5	98.93 %	5.00
PORT.DERBY	3291.5	39.9	76.41 %	3.88

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1736.54	1.45	0.00	0.00
TINDAL	1245.30	4.65	0.00	0.00
DERBY	1862.04	106.76	0.01	0.07
LEARMONTH	1081.51	44.53	0.00	0.00

STATISTICAL SUMMARY FOR 35 TRUCKS (DERBY WITH BULK)
##

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	11474.5	260.3	66.27 %	0.10
PORT.HEDLAND	3181.6	42.0	91.67 %	0.67
PORT.DERBY	3426.2	52.5	78.42 %	4.44

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1731.17	6.31	0.00	0.00
TINDAL	1248.03	11.14	0.25	0.74
DERBY	1830.81	117.93	0.00	0.00
LEARMONTH	1273.21	20.12	0.00	0.00

STATISTICAL SUMMARY FOR 40 TRUCKS (DERBY WITH BULK)
##

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	11595.3	321.2	59.38 %	0.06
PORT.HEDLAND	3168.4	39.5	77.74 %	0.07
PORT.DERBY	3411.2	53.3	77.83 %	3.84

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1731.67	5.84	0.00	0.00
TINDAL	1250.54	9.32	0.23	0.73
DERBY	1861.38	97.88	0.00	0.00
LEARMONTH	1299.60	14.43	0.00	0.00

STATISTICAL SUMMARY FOR 45 TRUCKS (DERBY WITH BULK)
##

PORT	MEAN STOCK	SD STOCK	TRUCK USE	TRUCK QUEUE
PORT.DARWIN	12372.2	514.1	51.34 %	0.02
PORT.HEDLAND	3167.7	32.1	69.58 %	0.00
PORT.DERBY	3358.8	37.0	77.42 %	4.61

BASE	MEAN FUEL	SD FUEL	MEAN IDLE TIME	SD IDLE
DARWIN	1738.08	1.01	0.00	0.00
TINDAL	1265.95	3.34	0.03	0.15
DERBY	1823.26	120.11	0.00	0.02
LEARMONTH	1312.77	11.81	0.00	0.00

Appendix G: Sample Routine for Iterative Terminal Input

```
ROUTINE INTINFO
  DEFINE PLACE, COLON AS TEXT VARIABLES
  LET COLON = ":"
  PRINT 2 LINES THUS
 ENTER THE NO. OF PORTS IN THE AREA OF OPERATIONS:

  READ N.PORT
  CREATE EVERY PORT
  SKIP 1 OUTPUT LINE
  FOR EACH PORT
     DO
        PRINT 3 LINES WITH PORT THUS
 ENTER THE PORT NAME, THE STORAGE CAPACITY, THE INITIAL FUEL STOCKS,
       AND THE REORDER POINT FOR PORT NO. *:

        READ PT.NAME(PORT),
             PT.CAPACITY(PORT),
             PT.STOCK(PORT),
             PT.REORDER.PT(PORT)
     LOOP
  PRINT 2 LINES THUS
 ENTER THE NO. OF AIR BASES:

  READ N.BASE
  CREATE EVERY BASE
        PRINT 7 LINES THUS
 ENTER THE FOLLOWING DETAILS FOR EACH BASE:

  BASE NAME, PORT NAME, FUEL STORAGE CAPACITY, INITIAL FUEL QUANTITY,
  AVERAGE DAILY DEMAND, DISTANCE FROM THE PORT, AND MINIMUM RESERVE.
          (NOTE: THE PORT NAME ENTERED HERE MUST BE IDENTICAL
                 TO ONE OF THE PORT NAMES ENTERED PREVIOUSLY.)

  FOR EACH BASE
        READ BA.NAME(BASE),
             BA.PORT(BASE),
             BA.TANK(BASE),
             BA.FUEL(BASE),
             BA.DEMAND(BASE),
             BA.DISTANCE(BASE),
             BA.RESERVE(BASE)
  CREATE EVERY SHIP(1)
  PRINT 2 LINES THUS
 ENTER THE NUMBER OF SHIPS AVAILABLE:
```

```
  READ U.SHIP(1)
  CREATE EVERY TRUCK(N.BASE)
  FOR EACH BASE
     DO
        PRINT 3 LINES WITH BA.NAME(BASE) THUS
 ENTER THE NUMBER OF TRUCKS AVAILABLE TO SERVICE:
                **************

        READ U.TRUCK(BASE)
     LOOP
  RETURN
END
```

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In northern Australia, prospective economic development is unlikely to create a distributed network of aviation turbine fuel storages sufficient to support Australian Defence Force operations in an emergency, and Defence investment in fuel storage facilities and distribution resources might be required. This thesis project was an effort to identify the key relationships in the operational fuels system, and to create a decision support system capable of indicating broad relationships and tradeoffs between decision variables. To answer investigative questions arising from a broad system review, relevant literature was examined, indicating a need to focus on the distribution system with five key elements: (1) demand, (2) bulk seaboard storage facilities, (3) base storage, (4) transport resources, and (5) transport infrastructure. A simulation program was developed to directly represent system dynamics for distribution from bulk to base storage. Subject to correcting of input statistics, the results could be used to inform Defence decisions on facilities construction, and investment in transport resources. With recommended enhancements, the model could potentially be used to inform Defence contributions to national and international policy considerations.

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